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THE RESEARCH PHASE OF THE AASHO ROAD TEST[a]

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(Proc. Paper 1795)

The background of the AASHO Road Test and a comprehensive description of the project have appeared in Civil Engineering. This report is concerned with the research that is the project's reason for being.

No research has ever been undertaken by highway engineers that even approaches the scope and magnitude of this project. The massiveness of the test coupled with the demands of the sponsors and the Congress for speed in getting out the results have made necessary some radical revisions in the thinking of the staff as related to highway research in general and to this job in particular. These changes in approach to highway research may in themselves be an important contribution of the project to highway researchers.

The advantages offered by modern techniques of experiment design and analysis and by modern instruments and data reduction equipment are just beginning to be exploited by highway engineers. Only a scattering of papers at the Highway Research Board have shown recognition of these things. But, by and large, the investigator had insufficient funds to do what he knew he should do, and usually ran into apathy if not downright opposition from his sponsors. The publicity that this project is bound to receive should bring these things to the attention of engineers and administrators at all levels. Of course, it remains for the job to be well done—if it is not, highway research may not change pace with the times. It may actually be set back due to the lack of confidence in research that is bound to accrue in the minds of administrators.

Thus, the research staff feels a two-fold responsibility—first, to the Sponsors who want to learn something from the test and second, to the highway researchers in general who are trying to do a man's job on a boy's allowance.

In simplified form the first objective of the road test asks for significant relationships between performance and traffic for pavements of certain designs under controlled truck traffic of certain loadings. This is by far the

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a. Presented at the convention of ASCE, Chicago, Ill., February 27, 1958.

1. Chf. Engr. for Research, Highway Research Board, AASHO Road Test.

important objective of the test as evidenced by the fact that most of the test sections and therefore most of the cost of the project are made necessary because it is included.

Near the beginning of this objective is the work "significant." In the past an engineer has said a relationship is significant on the basis of his judgment. In the judgment of another engineer it may have been not significant. Neither of them could prove his point. In the AASHO test the word will be used in a mathematical sense. That is, if a relationship is said to be significant, there is a stated probability that it is truly so within the environment of the experiment. A significant relationship may be defined as one in which the effects on one variable are known to be caused by the other variables with a specified degree of certainty. Obviously, then, the writers of the Road Test objectives were wise to include the word "significant" for without it the results of the test could be challenged successfully by anyone with an axe to grind. However, as long as the findings are confined to relationships that meet the mathematical tests for significance, special interests will have to look elsewhere for ammunition, and engineers will have little trouble in deciding for themselves which findings are applicable to their own work.

To make it possible to make statements as to significance of relationships the experiment must be designed in accordance with certain principles from the science of mathematical statistics. To insure that this would be done at the AASHO Road Test, the Highway Research Board, upon the advice of its parent organization, the National Academy of Science, established a panel of national authorities in this field immediately after accepting the responsibility for the project. Dr. Paul Irick, an authority in this field in his own right, joined the staff in 1955. The objectives as stated by the original working committee of the sponsor and as inferred from the original experimental layout were restated, and after months of hard work on the part of the staff with the advice of the Statistical Panel, the National Advisory Committee accepted a revised experiment design.

This design under which the test road is now under construction embodies the principles of scientific experiment design that make possible the isolation of experimental error, the elimination of systematic bias, generalization at least within the immediate area of the project and the consequent ability to make statements of significance. These principles, as applied to the Road Test, involve randomization in the layout of the experimental units and randomization of other processes whenever economically practicable, limited actual replication of test units and the use of factorial designs to strengthen the analyses. The analyses are strengthened through the use of factorial layouts because they permit study of all possible interactions and because they generally provide what may be thought of as hidden replication. That is, the effect of extra test sections is obtained without the cost of building them.

The increase in number of test sections made necessary by the use of complete factorial experiments in each test loop and their construction in random order undoubtedly added to the cost of the project. How much is not known, but it is clear that the project would have been extremely vulnerable if these principles had not been followed.

In the principal experiment, as it is now conceived, there are 8 independent variables. These are axle load, axle spacing, number of load applications, surfacing type (portland cement or asphaltic concrete), concrete reinforcement (plain or reinforced), surfacing thickness, subbase thickness, and

base thickness. Side experiments include consideration of base type, shoulder pavement width, and bridge studies.

Tests under traffic will be conducted in five test loops of which four will have two tangents 6800 feet long and one will have 4400-ft. tangents. A sixth loop will be constructed to permit auxiliary studies on pavements not subjected to traffic.

The basic experiment design permitting the most rigid analysis is the complete factorial where every level of every controlled factor is found in combination with every other level of every other controlled factor. These designs are located in each tangent on the project so that the relationships between a given load and the behavior of pavements subjected to that load will be well established. There are smaller complete factorials where identical sections are located in different loops. Here comparisons can be made of the relative behavior of identical sections under different loads.

Early in the planning of the project it was recognized that there was neither money nor space to include studies of new untried products or construction techniques. As stated in the first objective, it is desired to find how best to build pavements with materials at hand to carry the traffic most effectively. Thus the variables listed above that are included are those considered most important by a great majority of the sponsors of and advisors to the project. Of course, it was recognized that a highly important variable, that of embankment soil type, could not be included without a tremendous increase in cost. On the other hand, the findings of this test can be used to simplify the design and thus reduce the cost of future tests on other soil types and in other climatic environments.

The performance of a pavement, as is the case with almost any manufactured product, unfortunately, in a way, is a subjective thing. There is no instrument or device that can be plugged into the pavement from which can be read a number in performance units. Performance has many components. How these components are combined and what weight to give each of them in deciding how well a pavement performs can never be anything but a matter of judgment. No matter if the judgment is that of the researcher, an independent group of experts, or the riding public, it is still solely judgment.

The dependent variable in the Road Test which in effect, will be plotted as ordinate against the other variables in studies of the relationships called for by the first objective, is a performance index. It will be made up of those elements of performance that can be measured on the test sections such as longitudinal and transverse profile of the surface, cracking, and faulting. In order to determine whether or not the performance index is a valid measure of performance or not, the values it produces for a given pavement will be compared with the mean rating of that pavement made by members of a panel of pavement experts. This most important panel has been appointed and the ground rules for their operation have been under study for some time. Mathematical techniques are available for the simultaneous derivation and validation of the performance index.

Once the index is established as the dependent variable in the test, the analysis is reduced to a matter of finding appropriate mathematical models to represent the relationships sought under the objectives. Analysis of the data with respect to these models will determine the extent to which the controlled factors affect the performance index. Thus the evaluated models become the significant relationships asked for in the objectives of the Road Test. It remains, however, for the research engineers to examine the relationships

obtained to find the most effective ways for presenting them graphically and to find whatever information they contain that may lead to better understanding of the mechanics of pavement behavior. The relationships may also provide keys to improved structural design techniques for pavements.

The main dependent variable (the performance index) and its utilization has been discussed in general terms. More specifically, a "present serviceability index" will be used to define the ability of any section to carry traffic. This present serviceability index will be validated through the use of a present serviceability rating obtained from the panel of experts. Now the present serviceability index is derived from measurements of elements of behavior, roughness, cracking, etc. Once a satisfactory index is obtained, other models may be analyzed using the design variables, such as thickness and load applications, and the measurable environmental variables such as soil moisture content, to make up new relationships between these variables and the manner in which the pavement has performed.

The Road Test would be incomplete if the analyses were to stop at this point. It is necessary to go one step farther and develop what shall be called a future condition index that can be used to predict the condition of a highway at some future date if it is to be subjected to known loading and environment. Some of the elements of this index may be the same as are found in the present serviceability index, notably design considerations. They may, however, also include one or more other measurable functions, such as strain or deflection, that have been shown to be useful as a substitute for independent variables whose values cannot be determined such as moisture content. The validation of the future condition index will be accomplished by comparing conditions predicted by the index for dates in the future with conditions that actually exist when the future dates are reached. No one connected with the Road Test expects to be able to establish strong future condition predictors in a test involving only two years of traffic, but valuable information as to the form of model and significant elements of such an index should be obtained.

Another important function of the research will be to find as many useful relationships as possible between those measurements known to be effective in predicting pavement behavior, such as stresses, deflections, etc. and the design features of the pavement. If it is demonstrated that behavior is correlated with strain, for example, it will be useful to designers to know what effects various changes in design will have on the strains that will occur under load.

Although it is difficult to make clear in a short time the mechanisms by which all of these things will be accomplished in the Road Test, the course is clearly plotted. Much of the staff effort over the past two and one-half years has been directed towards clarification of these concepts. It is now known, to a large degree, just what measurements will be made, when and where they will be made, just how the data will be reduced and just what analyses will be made. Of course, the programs and schedules are completely flexible—it is known that a great many changes in plans will be necessary as the testing program gets under way. But by and large, the overall approach to the problem will remain unchanged. The experiment has been well designed and the analyses are largely suggested by the design. All that remains prior to analysis is to operate the test traffic and collect the data.

The test traffic will consist of trucks and tractor-semi-trailer combinations. One lane of the thinnest pavement loop will be subjected to traffic consisting solely of one pickup truck per minute 15 hours per day, 6 days a

week for two years. Each axle of the pickup truck will be loaded to 2000 pounds. The other lane of this loop will be subjected to 6000 pound axle loads at the same average rate. The heaviest pavement loop will contain one lane under tractor-semi-trailers with heavy single axles loaded to 30,000 pounds and one lane with tandem axles loaded to 48,000 pounds. Intermediate loads will be carried by the vehicles in the other loops and the rate of application of heavy axle loads will be the same in all loops.

The vehicles will be loaded with blocks with a density of about 80 pounds per cu. ft. so that the center of gravity of the load is higher than it would be if concrete at 150 pounds per cu. ft. were used. Thus, the loads will more nearly simulate average conditions on the highway than the concrete loads used in previous road tests. The vehicles will be operated by drivers from the Army Transportation Corps in a controlled pattern of transverse position simulating the transverse position pattern found by the Bureau of Public Roads to exist in normal truck operation on high type highways throughout the nation. They will operate at 30 M.P. H. over all test sections. This speed has been found to produce strains and deflections in smooth pavements only slightly greater than those found under 60 M.P.H. speeds, and was chosen to permit the use of turnarounds of reasonable dimensions at the ends of the test tangents.

Certain measurements will be made to aid in establishing the condition of the test sections and to help in the determination of the nature of changes in condition. To obtain these measurements and to process the data will require over a million dollars worth of instruments and devices. Such a large cost may suggest at first glance that every conceivable variable in every test section will be measured. This is far from the case. Only those variables that have been shown in previous research to correlate with behavior will be measured, and then in many cases they can be measured only in a few selected sections within the test. Even so, it has been necessary to develop new transducers and associated electronic equipment for nearly all measurements, since devices with the required characteristics simply were not available. A large part of the million dollars was used to cover the cost of development work on this new equipment. A very competent panel of authorities on instrumentation guided the staff in this work and about three-fourths of the more complicated devices were developed off the project under contract with a systems engineering firm, Reed Research, Incorporated, of Washington, D. C. Data processing electronics are being furnished largely by a subcontractor under Reed, Electronic Engineering Company of California.

The following lists the principal measurements that will be made:

1. Curvature of the asphaltic concrete surfacing of flexible pavement under full speed traffic.
2. Deflection at the surface and at subsurface interfaces between pavement layers under full speed traffic.
3. Deflection at very slow speeds at the surface of flexible pavement.
4. Deflections and strains near the corners of rigid pavement slabs.
5. Strain distribution under static loads in certain concrete slabs.
6. Subsurface pressures at slab-subbase interface in certain concrete slabs.
7. Subsurface pressures in selected flexible pavements.
8. Longitudinal profile of the surfaces in the wheel paths.
9. Transverse profile of the surface.
10. Permanent (as opposed to transient) deformation at subsurface levels in flexible pavements.

11. Temperature above, on, and under the surface throughout the project.
12. Strains and deflections—dynamic and static—in test bridges.
13. Dynamic wheel load. The load actually applied by a wheel as it passes a point where other measurements are being made.
14. Depth of frost penetration.
15. Total upward and downward deflection occurring at the corners of selected concrete slabs during an interval (usually one day).
16. Automatic scheduling and recording of transverse vehicle placement history.
17. Precipitation, humidity, wind, and air temperature.

Some of these measurements are made by transducers located in the pavements the output of which is indicated in an instrument van parked alongside a test section. Here it may take a week or two to cover all instrumented test sections in the project. Other devices run along the surface of the test pavements recording certain phenomena as they go. Notable in the second category are the automatic Benkelman beam, a device designed to read surface deflections every 25 feet as it moves down the road at 3 M.P.H., and the longitudinal profilometer which, in effect, plots the true profile of the road as it travels at 10 M.P.H. This last has been by far the more difficult instrumentation problem.

Obviously, a tremendous mass of data is accumulated by automatic equipment of this sort. Neither time nor personnel are available to read oscillograph charts, pick off maximum deflections or strains and record them by hand, so all of these things will be done automatically. The data from most measurement systems will be translated to the desired units in the field equipment, digitized and punched on paper tape. In the headquarters processing center the tapes will be fed directly to a digital computer or to a tape to card punch to prepare IBM cards which will be used for various sorts and for summary listings.

A small general purpose computer will be available for summarization work and for so-called open shop use by the research engineers at the project. Most analyses will be performed here. Some analyses too large for this computer will be performed by the Purdue Statistical Center on their larger computer under contract to the project.

Most of what has been reported about the pavement research also applies to the studies of test bridges in the road test except that it was not felt necessary to design the bridge experiments for statistical analyses. Rather there are 16 individual case studies in the bridge program and the emphasis in the analyses will be on validation of equations already established through prior research. The bridge spans are designed for high stresses in the steel and concrete and some failures under the test traffic are expected. The nature of the failures will be studied carefully.

While this is a relatively big highway research project it is only a start. All highway research underway today adds up to less than one-tenth of one per cent of the expenditures for highways. The rate considered necessary for survival by industry is nearer to 5 per cent for research, fifty times the present highway rate. Since one person of every seven in this country derives his income from some phase of highway transportation, the number of stockholders in this enterprise is large. It is time they took a close look at the situation and determined whether or not they may be better served through better highways developed as a result of more comprehensive research.

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THE HISTORY OF ROAD TESTS

E. A. Finney[1]
(Proc. Paper 1796)

SYNOPSIS

This report traces the construction of different types of road tests in the United States from the latter part of the 18th century to the AASHO Road Test now under construction in the State of Illinois.

Five distinct periods of road building history in this country are mentioned. Road testing is discussed in relation to these periods.

Whenever possible, a brief description is given for each road test project including the date of construction, purpose, scope and reported findings.

INTRODUCTION

This is a history of road tests in the United States dating back to the latter part of the 18th century. It provides a summary of road test information as related to different eras of highway transport developments in this country.

In general, road tests can be grouped into three general classifications: namely, 1) Trial Roads; 2) Experimental Road Tests; and 3) Controlled Traffic Road Tests. An explanation of each classification follows.

1. Trial Roads are sections of rural highways constructed for the first time, employing new materials and construction in accordance with prepared specifications. For example, in this category would be found the first broken stone road completed in 1796, the first brick road in 1893, and the first concrete road in 1909, and others.
2. Experimental Road Tests are a logical outgrowth of the trial road, including all road test projects in which have been incorporated during

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their construction, several factors of highway design or road construction of technical importance, for study under recognized research procedures and instrumentation. Observations may continue for several years before final determinations can be made and the results evaluated.

3. Controlled Traffic Road Tests are those in which the test traffic is controlled as to magnitude, frequency, and placement of axle loads. It is the intent in such projects to shorten the testing period normally encountered in long range experimental road tests, by accelerating the traffic effect through introducing many frequencies of heavy axle loads in a relatively short period of time.

No attempt will be made in this paper to describe in great detail the various technical aspects of the many completed road tests, because such facts are adequately covered in available literature.

The impartial study of different types of highway surfaces has been going on for a great many years in an attempt to discover the most satisfactory pavement or materials for construction. In America, such studies date back almost a century.

The highway engineer, searching for answers to problems in highway design and construction, seeks technical information through one or more of the following media:

1. By resorting to field condition surveys of existing pavements and appraising previous construction experience, or by theoretical analysis and laboratory experimentation.
2. By means of observations from trial roads or long-range experimental road tests subjected to normal traffic conditions.
3. By conducting accelerated controlled traffic tests on existing or specially constructed pavement sections.
4. By extracting technical information from existing research reports.

Road test research is intimately associated with the economic and transport conditions which prevailed in different periods of American history. Up to 1958, there have been five such periods. They may be broadly outlined as follows:

1. (1620-1800)—The Foot and Horseback Era. Travel prior to the nineteenth century was mainly on foot or horseback, and roads were either trails or crude wagon roads rarely improved beyond the state of nature.
2. (1800-1900)—The Turnpike and Dark Age Era. The nineteenth century witnessed some progress in the use of broken field stone or gravel and even wooden planks for road surfaces in an attempt to provide roads which would resist the destructive effects of weather and horse drawn vehicles. Road authorities began to experiment with materials and construction methods to develop an all-weather road.
3. (1900-1920)—The "Out of the Mud" Era. During the first twenty years of the twentieth century, the automobile and the truck developed as a predominating factor in future highway transport, thus creating new problems in highway design and construction, and the necessity for all-season roads.
4. (1920-1945)—The Dawn of Highway Systems and Highway Research. This period witnessed the beginning of a nationwide program of highway

construction by the states through the availability of federal funds and revenues from motor vehicle taxation. Also, highway research of large scale proportions was started under the auspices of the Bureau of Public Roads, the Highway Research Board, and also by many universities and state highway departments.

5. (1945-?)—The "Out of the Muddle" Era. This postwar period will be remembered for its traffic jams, parking problems, and the beginning of great systems of expressways, toll roads and freeways, as well as the rehabilitation of many miles of obsolete primary and secondary highways and the construction of tremendous highway bridges.

The following discussion of road tests will be correlated with the eras of road-building history mentioned above.

The Foot and Horseback Era—Prior to 1800

It has been said that organized road improvement in the United States started with the Philadelphia and Lancaster Turnpike Road, privately built and completed in 1796.

This pike was the first long-distance stretch of broken-stone and gravel surface in this country to be built in accordance with plans and specifications. This road might also be classed among the first Trial Roads, thus opening the way for private turnpike or national road construction projects which followed in the nineteenth century.(1)

The Turnpike and Dark Age Era—1800-1900

The first half of the 19th century constituted the turnpike era in America. The need to connect growing settlements in the west with the seaboard created a demand for better roads. The success of the Philadelphia to Lancaster Turnpike project created the turnpike craze which reached its zenith in 1836, at which time the railroad became the favored mode of land transportation. From 1836 to 1878, public wagon roads deteriorated into a wretched condition often referred to as the Dark Ages of highway construction. The bicycle craze of the 90's started the Good Roads Movement, and the advent of the automobile in 1892 created the need for hard surfaced roads.

Road tests during this era were confined primarily to constructing Trial Roads and locating short experimental road sections in cities and villages to study the performance of different types of road surfacing materials. They were constructed and observed by local municipal authorities or county supervisors who acted in accordance with results to improve local conditions. Because of the lack of funds, such experiments were generally limited to trial road sections a few hundred feet in length and called sample pavements, investigational roads, model surfaces, or demonstration pavements. Municipal authorities were concerned by the expense of preserving busy roads and streets and tried to devise harder and more durable surfaces. The experiments were not limited, of course, to materials now considered orthodox for road building. Among others, surfaces before 1900 included cork, a wide selection of wood blocks, sheet rubber, compacted sawdust, oyster shells, stone blocks in great geological variety, metal plates and rails, numerous forms and shapes of bricks, and finally, glass cubes processed from broken bottles and smashed windowpanes.

In addition to the experiments backed by local government and by paving materials groups, not a few inventive engineers independently risked their reputations and capital by putting down stretches of street surface incorporating personal innovations in materials or construction methods. The men who built these experimental pavements were proud of what they considered a progressive, enlightened approach to road building.

Contemporary engineering magazines carried frequent references to these county and municipal experiments. In 1870, five hundred yards of a new type of asphalt was tried in Newark, typically in front of City Hall, and performed well.(2) On Sixth Street in Philadelphia beside Independence Hall, a successful experimental surface was laid in 1873, demonstrating "the durability of asphalt under severest traffic changes."(3) Between 1871 and 1874, Engineering News, told its readers, "Washington, D. C. experimented with every known type of pavement."(4) In Cleveland, the approach to the mausoleum of the assassinated President Garfield, on Euclid Avenue, had asphalt and wood sample sections which were described shortly after installation as being "in execrable shape . . . all cut to pieces."(5)

Other contributions to the science of road building appeared: the bituminous pavement in 1834, the steam shovel in 1835, the first cast iron bridge in the United States in 1839, blasting powder in 1856, the jaw rock crusher in 1858, the steam road roller imported from England in 1869, and manufacture of portland cement began in 1871.(6)

Four new types of road surfacing materials made their appearance in trial projects and were generally accepted for future use. The first macadam surface in this country was completed between Hagerstown and Boonsboro, Maryland in 1823. Another project following the Macadam principle was completed in 1830 by the government on the Cumberland Road. The first brick surface on a rural road in this country was completed in 1893. It was laid on the Wooster Pike near Cleveland, Ohio. The first portland cement concrete street pavement was laid in Bellefontaine, Ohio in 1891. A small stretch of concrete alley previously had been laid in 1890 in the City of Connorsville, Indiana. In 1889, sand-clay roads made their appearance in South Carolina where frost did not penetrate the ground to any appreciable depth. They were adequate for light traffic and less dusty and more resilient than macadam. They became widely used in the South Atlantic and Gulf States.(7)

For two decades after the Civil War, road testing by local governments and trial construction by materials firms and individual engineers resulted in generally improved pavements for some metropolitan areas, the emphasis being on wear-resistant surfaces. Paradoxically, it was not the need for improved transport of passengers and freight that finally produced widespread public demand for better pavements but, instead, the outcry from thousands who wanted to enjoy the pleasures of simple tourism.

The whole nation was infected by the great bicycle craze in the 1890's. Altogether, more than 4,000,000 bicycles were sold in that period, mostly to adults. One historian recalls, "The bicycle launched hundreds of thousands of people into a new kind of fun and a new mobility; gave people a sense of relief and freedom. Life had been circumscribed without much social interchange between one town and another, fifteen or twenty miles away. True, there were railroads, but on a bicycle you could go where you pleased . . . fix your own schedule."(8)

Given the enthusiasm of the cyclists, it is easy to imagine their impatience and frustration with the miserable streets and roads on which they had to

travel. Their solution was, of course, forming the League of American Wheelmen, parent organization to the Good Roads Movement.

Following hard on the heels of the cycling craze, came the fast-developing interest in automobiles. Together, the cycle and the car created an irresistible demand for hard-surfaced, all-weather roads.

The Good Roads Movement of the Nineties received enthusiastic support from the railroads. By 1900, the country had again reached a stage in its development where economic forces caused a strong demand for rural highways. With cities growing, more food had to be grown on new farms at ever greater distances from the railroads. Thus, the need was seen to get the farmer out of the mud, and the demand was for all-weather roads from farm to railroad.(9)

Just as road testing began to accelerate when town-dwelling cyclists and auto owners discovered the pleasures of outings in the country, interest in paving experiments was even greater when farmers and railroadmen discovered the economic advantages of transporting heavy loads to the station and the town on better roads.

The most important single episode in this era of highway history was the establishment, in 1893, of the Department of Agriculture's Office of Road Inquiry, forerunner to the Bureau of Public Roads. The statute creating the Office read, in part, "To make investigations in regard to the best method of road making and to disseminate information on the subject." The early program included testing road traction in 1895, and the construction of object lesson roads.

The Office of Road Inquiry was also under instruction to cooperate with state agricultural colleges and experiment stations. The entire field of road testing gained when the prestige and objectivity of the academic world were added to pavement experimentation. The Road Office's first object lesson road was built in 1897 at the New Jersey State Agricultural College and Experiment Station in New Brunswick, New Jersey. The purpose of this test road was to show the people that a road could be built with crushed rock which would be good all year around.(10)

In addition to these extensions of road experimental activity by the Office of Road Inquiry, a new series of road studies began as state highway departments were established at the turn of the century, with their broad emphasis on inter-community travel.

In 1896, sample half miles of macadam road were built by Rhode Island to demonstrate the modern methods of building macadam roads and in order that the advantages of building macadam roads should be appreciated by people throughout the State. Cost information was released as each test pavement was installed and, in each case, emphasis was placed on local traffic and terrain.(11)

A definite shift of emphasis in road testing occurred about 1880. Highway technology at last began to emerge from the American Dark Ages. Where earlier work centered on finding materials for a permanent surface, now the problem was discussed in terms of the whole pavement structure, of foundation and drainage, and of the relation between paving courses. More specifically, where road tests had been undertaken before by public authorities to determine means of reducing costs and by private interests for profit, now experimental roads were put down by state and federal agencies to impress road users with the appearance and advantages of soundly built, smooth-riding pavement.

The "Out of the Mud" Era—1900-1920

The period from 1900 to 1920 was one of trial and error in highway construction. Pavements were built with radically shaped cross-sections depending on the whims of the engineers in charge. No great amount of basic technical information was available on which highway engineers could base their design or construct pavements with any degree of certainty as to future pavement performance. In addition, they were primarily interested in getting vehicles out of the mud. Traffic as we know it today was beyond comprehension. In this period, road tests were constructed with more stress being placed on the economic construction of more permanent highways on the state and county level.

In 1905, the Office of Road Inquiry was merged with a government testing laboratory and renamed the Office of Public Roads. One of the enlarged agency's first projects was a series of experiments with burnt clay roads in Mississippi.(12)

Also in 1905, the Office of Public Roads experimented in the use of coal tar and crude oil for treatment of worn out macadam roads for the purpose of reconditioning them and to stop the dust nuisance. Experimental trial road sections were constructed in Tennessee and Texas with good results. Meanwhile, the new state highway organizations were active; in 1906, trial road tests in Rhode Island demonstrated conclusively the advantage of constructing bituminous macadam surfaces using either the mixing method or the penetration method.(13)

By 1906, Illinois' new highway department, specifically chartered "to investigate and make experiments as required", had built several long experimental roads, and was completing an experimental 40-foot reinforced concrete bridge to be used exclusively for load testing.(14)

The first municipality in North America to pave streets extensively with portland cement concrete was Windsor, Ontario, which laid 32,000 square yards in 1907. The first pavement on a county road of portland cement concrete was opened to traffic in October, 1908 in New York State. Wayne County, Michigan was the first to surface a rural public road in the United States with portland cement concrete in 1909. Concrete produced a road surface comparatively low in first cost, of good durability, low maintenance cost, ease of traction, and freedom from dust and mud.(15)

In 1909, the Rhode Island Highway Department built an elaborate 11,870-foot test road including several types of bituminous macadam treatments, with the object of "determining the most economical method of construction for modern traffic."(16)

By 1912, road builders were placing as many materials as possible in combination base courses in their test projects. New York City built a 30-block-long experiment on Second Avenue where most of the vehicles still moved on iron tires. The test included sheet asphalt, asphalt blocks, medina sandstone cubes and blocks, wood blocks and granite blocks.(17) In the same year, the Bureau of Public Roads installed a 6,194-foot experiment in Montgomery County, Maryland composed of thirteen sections including bituminous concrete, cement concrete, oil cement concrete, and brick.(18) The first important appearance of portland cement concrete in road tests also occurred in 1912, when California authorities built a ten-section pavement to "determine the applicability of concrete to California climate, traffic and subgrade conditions, as well as the most economical design." According to an

account of construction, "various types of surface were used in an attempt to minimize the hard, slippery, inelastic and glaring surfaces usually attributed to concrete."(19)

The first 20 years of the twentieth century may be considered a period of preparation for the large scale road-building which followed the end of World War I in 1918. This period witnessed marked changes in types of roads built, in machinery for building them, and in governmental organization directing the work. Through trial roads and experimental road tests, there was a marked development of new types of road construction. The period also marked the important change in road construction from the gravel and water-bound macadam popular in the preceding 100 years, to such hard surface types as bituminous macadam, bituminous concrete, brick, portland cement concrete, and sheet asphalt.

The Dawn of Highway Systems and Highway Research—1920-1945

In the early 20's, highway construction increased rapidly to meet the demands of the upward trend in motor vehicle manufacture and use, assisted by additional federal appropriations and highway revenues. By the mid-30's, the states had achieved their objective of completing a system of two-lane roads connecting the centers of population but the need had become apparent for highway improvement on a much more comprehensive and broader scale.

This tremendous highway construction and vehicle increase spiral of the 20's and 30's created many new problems requiring engineering data not available in the technical literature of the times. For example, test information was needed with respect to the supporting power of various subgrade soils, the value of stresses and deflections induced in rigid and flexible pavements by axle loads on moving vehicles, the effect of temperature and moisture on the expansion and contraction of road surfaces, the effect of traffic on the performance of pavement surfaces, the distribution and effect of loads on bridges, and many other factors. Consequently, in 1920 a nationwide program of research was launched under the auspices of the Bureau of Public Roads and the Highway Research Board, assisted by many universities and state highway research organizations. Included in this research endeavor was one controlled traffic road test and several outstanding experimental road test projects covering both portland cement concrete and bituminous pavement construction, as well as many other lesser road research projects which have contributed greatly to the store of technical literature.(20)

Bates Road Test

Starting about 1920, several states began to build concrete pavements on a large scale for heavy-traffic highways. Among those states was Illinois which at that time was contemplating an expenditure of $100,000,000 for a road improvement program. They deemed it unwise, however, to undertake a program of this size without definite scientific knowledge of the behavior of certain pavements under truck traffic and rural conditions, and without definitely knowing how to design pavements to sustain truck traffic. Consequently, they decided to build a road test project of their own at a cost of several hundred thousand dollars. The result was the classic Bates Experimental Road, constructed and operated at Bates, Illinois between 1920 and 1923. This was the first controlled traffic road test.

Factors under study included subgrade moisture, soil-bearing power, effects of temperature, investigation of stress in concrete pavement corners, the effect of controlled traffic of different wheel loads, fatigue of concrete, and various curing experiments.

The Bates Road Test project was about two miles in length and included 63 test sections, each approximately 200 feet long and representing all types of pavement surfaces of that time; several thicknesses of each type were used so that when trucks were operated over the road with increasing loads, the capacity of each section, measured in terms of weight and number of trucks, would be plainly obvious. The project produced a large amount of useful information which has persisted in concrete pavement construction and design practice even down to the present day.(21)

The Bates Road Test produced the first design criteria for determining the thickness of a concrete pavement for a known wheel load—the Older Corner Formula $d = \sqrt{\frac{3W}{S}}$ where d equals thickness in inches, W equals wheel load in pounds, and S equals the flexural strength of the concrete in pounds per square inch. It was also determined from these tests that a pavement thickness of at least eight inches would be required to support the 8,000-pound wheel loads of that day.(22)

Many of the early concrete roads built prior to World War I had uniform slab thicknesses of from 4 to 6 inches. The impact of the solid rubber truck tires then in use caused extreme damage to the highways. As a result of the Bates Road Test, thickened edges of 7, 8 and 9 inches became prevalent.

The success of the Bates Road Test encouraged the Bureau of Public Roads to employ H. M. Westergaard to make a theoretical stress analysis of concrete pavements, which he completed in 1925 and later modified to include pavements for airports.(23) Improvements in the Westergaard analysis by Gerald Pickett for the Portland Cement Association have given highway engineers a theoretical method for determining the thickness of concrete pavements for sustaining modern traffic.(24)

The Pittsburgh, California Road Test

In the early Twenties the lack of technical information for building durable highways also prompted the Columbia Steel Company of Pittsburgh, California to construct a small test road embodying different types of pavement cross-section, with special emphasis on determining the efficiency of both reinforced and nonreinforced pavements of variable thickness and design on certain types of subgrade soils. This work was started in February, 1921 and completed in 1922, running concurrently with the Bates Road Test.

The Pittsburgh Road Test project consisted of a loop section approximately 560 feet in length, containing 13 test sections, each approximately 100 feet in length. This project also played its part in adding to the limited supply of technical information at hand.

The results of the Pittsburgh Road Test were not finally conclusive although they were very helpful in serving to indicate more precisely the direction of future research. Refinements of the instrumentation methods used at Pittsburgh increased the value of future study of the behavior of road surfaces of rigid type. The effectiveness of longitudinal joints in preventing longitudinal cracks in either plain or reinforced concrete slabs was strongly indicated.(25)

Soil Stabilization

For many years, engineers have worked to develop a practical method of using common soils with certain amounts of portland cement or bituminous materials to produce an economical structural material of ample durability and hardness, to serve as a road base for secondary roads and, more recently, for base construction under concrete or bituminous concrete wearing courses.

During the 1930's, numerous road test projects were constructed to study the effectiveness of hardening soil with portland cement. Road tests were conducted in Illinois, Iowa, Michigan, Missouri, Wisconsin, Pennsylvania, South Carolina, and extensively in California. The specific objectives of the test were twofold: first, to mix cement with local fine grain soils for secondary road construction; and second, to mix cement with granular soils from stream beds or other materials of suitable nature at hand.(26)

Chemical Dust Palliatives

In 1931 and 1932, road tests were constructed in various parts of the country to secure data concerning the effects of dust-alleviating treatments upon soil binder and upon the preservation of the road metal in relation to the use of deliquescent salts and other materials as dust palliatives. These roads were located in South Carolina, Missouri and Nebraska.(27)

Bituminous Joint Fillers

Brick experimental roads were constructed by the Ohio Highway Department in 1933 and 1934 to study different types of brick joint fillers.(28)

Experimental Concrete Pavement

In 1936, Kansas completed the construction of an experimental concrete paving project located on highway US-10 East of Lawrence, Kansas. This experimental pavement, approximately five miles in length, was divided into twenty sections and on thirteen of these sections, studies of subgrade variations were planned. The pavement was built by Kansas in an attempt to find out why the concrete pavements were developing unusual roughness qualities in about one year's service. In addition to the study of warping, other factors in the design and construction of concrete pavements were included.

The project has resulted in many important research findings which can be applied to design and construction operations at any location, because the principles involved are basic to concrete pavement construction.(29)

The Arlington Test

Between 1930 and 1936, the Bureau of Public Roads carried on an extensive investigation of the structural design of concrete pavement at its experimental grounds in Arlington, Virginia. This work included the actual measurement of stresses occurring in concrete slabs of varying thicknesses due to imposed loads, temperature, and impact. It was intended to develop information that would be of assistance in the better understanding of the structural action of concrete slabs. The project included four main studies, as follows:

1. The effect of loads placed in various ways on pavement slabs of uniform thickness.

2. The behavior under load and comparative structural effectiveness of typical longitudinal and transverse joint design.
3. The "balance of design" or relative economy of typical pavement slab cross-sections.
4. The effects of temperature conditions and moisture conditions on the size, shape, and load-carrying capacity of pavement slabs.

The project consisted of ten full-size slabs, each 40 feet long and 20 feet wide. Test loads were applied by means of pressure jacks.

This research work resulted in establishing the reliability of the Westergaard Analysis for determining stresses in concrete pavement slabs. It also produced much needed technical information pertaining to joint design and warping stresses in concrete slabs. This information is the basis for modern concrete pavement design criteria.(30)

Air-Entrained Concrete

In the late 30's, the extensive use of de-icing salts for winter maintenance resulted in extreme scaling of concrete pavement surfaces, especially in the northern area of the United States. Scaling was encouraged by the presence of a thin layer of weak mortar which consistently formed on the concrete surface during construction. As a result, road tests were constructed in which various ingredients were incorporated with the cement and aggregates to produce a scale-resistant surface.

The earliest use of air-entrainment was in New York State in 1938. Between 1938 and 1942, there were 17 test pavements constructed in several northern states including New York, Maine, Pennsylvania, Massachusetts, Vermont, Michigan, Indiana and Ohio. The Michigan Test Road was approximately 8 miles in length and included for study many factors besides air-entrainment which were expected to produce a scale-resistant concrete surface.(31)

In 1939, Indiana constructed several concrete pavement test sections containing portland cement blended with natural cement containing a grinding aid. The purpose of this study was to determine the effectiveness of this method in producing a concrete with high resistance to freezing and thawing, and resistance to scaling caused by de-icing salts. The test definitely proved that the blended concrete resisted disintegration much better than the normal concrete used for comparison in the test.(32)

The Ohio Highway Department also constructed a concrete road in 1940 which contained 49 test sections. The principal test features were cements and combinations of different cements manufactured with and without air-entraining additives.(33)

These road experiments established beyond doubt that air-entrainment would do a remarkable job in improving the durability of concrete, provided that the air was entrained in the correct amount, and uniformly dispersed in the form of very fine bubbles throughout the concrete mass. Air-entrainment also improves workability, uniformity, and has other important features. At that time, air-entrainment was considered to be the most important single development in concrete technology for at least twenty years. Air-entrained concrete has now come to be widely used in all types of concrete work.

Bituminous Surface Treatments

In 1939, a ten-mile bituminous surface treatment road test was constructed in the northern part of Indiana on State Route No. 8. The purpose of this work was to study: 1) the effect of type of bituminous material and source of aggregate; 2) the effect on construction and service performance of the amount and method of application of the bituminous material and the size of both the covering and chipping aggregates. The general conclusion was that plant-mix method should be investigated for use in bituminous surface treatment construction.(34)

Pavement Jointing Road Tests

In the Thirties, considerable controversy developed among highway engineers and the Bureau of Public Roads concerning: 1) the need for expansion joints and proper spacing when used; 2) the necessity of expansion joints if contraction joints are used; 3) the amount of space necessary at expansion joints; 4) use of weakened plane or "dummy" joints; and 5) use of dowels in close-spaced contraction joints. Consequently, to settle the issues, the Bureau of Public Roads authorized the construction of several long-range experimental road tests located regionally throughout the United States.

In 1940 and 1941, each of the following states: California, Kentucky, Michigan, Missouri, and Oregon, in cooperation with the Bureau of Public Roads, constructed these experimental pavements several miles in length, embodying experimental features associated, in particular, with joint design and joint spacing in concrete pavements. There were also included additional features of design and construction of special interest to the respective States. These studies were supplemented by a special study of the structural efficiency of transverse joints of the weakened-plane type, to be made by the Bureau of Public Roads in the Arlington Tests.(35) These experimental pavements were subjected to normal uncontrolled traffic conditions, and the behavior of the test sections was observed over a long period of time. The findings from this work so far have resulted in marked changes in current State specifications for concrete pavement construction. The most notable change is the trend toward elimination of expansion joints in concrete pavements, except at critical locations where stress relief would be desirable. These projects are still under observation by the respective states. Periodic progress reports have been submitted by the Bureau of Public Roads.(36)

Hybla Valley Road Test

Interest in the problem of structural design of flexible pavements started during the war period, to a large measure associated with airport construction. However, a cooperative research project between the Highway Research Board, the Asphalt Institute, and the Bureau of Public Roads was started during the war period near Hybla Valley, Virginia, on a tract of government owned land about ten miles south of Washington, D. C. The project consisted of an oval tract with parallel tangents 800 feet long connected at the ends with curves of 200-foot radius. The purpose was to develop fundamental data on the load-supporting value of flexible pavement surfaces of various thicknesses and degrees of subgrade support. Testing was to be done by specially designed load-bearing test equipment and transient loads. The project furnished a great deal of technical information which has been especially useful in the formulation of future testing programs and for the

comparison and correlation of existing proposed methods of thickness design for flexible pavements.(37)

During this period road tests and supporting research made numerous outstanding contributions to highway progress.

1. Modern soil test procedures were developed which are in use at the present time.
2. Agreement was reached on the 9,000-pound wheel load as the economic standard upon which to base the design of nationwide systems of highways.
3. Thickened edge design was adopted for rigid pavements as based on the Bates Road Test.
4. Introduction of the soft pneumatic tires resulted from impact tests conducted by the Bureau of Public Roads in 1921.
5. Design criteria for concrete pavement were developed and substantiated by tests.
6. The principle of concrete air-entrainment was discovered and put to use in concrete pavement construction.
7. Expansion joints were found to be unnecessary in concrete pavements except at locations where compressive stress had to be kept within safe limits.
8. Granular sub-base courses were found necessary under concrete pavements to reduce and prevent pumping of the slabs.
9. Technology advances were made pertaining to the design and construction of bituminous concrete mixtures and surface courses.
10. The principle of soil stabilization was widely employed.

"Out of the Muddle" Era— 1945-?

With the beginning of World War II postwar period in 1945, highway engineers and administrators were faced with the following complex and comprehensive highway problems:

1. The responsibility for the following construction programs:
   a. Rehabilitating many miles of worn-out pavement surfaces.
   b. Constructing many miles of new highways on new rural trunkline systems.
   c. Rehabilitating some 35,000 miles of interstate highway systems which had become obsolete.
   d. Constructing many miles of new expressways in metropolitan areas to relieve traffic congestion which had developed under modern transportation requirements.
   e. Construction toll roads and freeways between cities or important centers of population.
   f. Constructing long high-level highway bridges at strategic locations.
2. The necessity for providing adequate pavement thicknesses to carry the load application frequencies associated with modern motor truck transportation. In this respect, the important pavement and bridge design factors needing verification by scientific investigation included the following:

a. Reliability of present design criteria in determining concrete pavement thickness.
b. Thickness requirement for granular sub-base material under concrete pavements.
c. Design requirements and spacing of joints in concrete pavements.
d. Economic justification of non-reinforced versus reinforced concrete pavement.
e. Numerous methods advanced for determining thickness requirements for flexible pavement construction.
f. Design procedures for bituminous wearing courses for flexible pavements.
g. Bridge design criteria in relation to fatigue under repetitive loadings, impact, deflection and vibration.

After World War II, several new road tests were constructed by certain States, as follows:

U. S. No. 41 Road Test

The State Highway Commission of Indiana and the Bureau of Public Roads constructed an experimental road test on US-41 in 1949 to study means of preventing pavement pumping on highways that carry a high volume of truck traffic. The project was divided into sections consisting of different methods of soil treatment materials and sub-base construction of different thicknesses. The project is still under observation.[38]

Continuously Reinforced Pavement

For a long time the desire of highway engineers has been to give the public a lasting, smooth-riding concrete pavement with low maintenance cost, and of economic design. This has resulted in the appearance on the highway scene of the so-called continuously reinforced concrete pavement requiring about double the amount of steel normally used in reinforced pavements, but with a reduction in slab thickness.

In this type of construction, the transverse joints are purposely omitted and sufficient longitudinal steel is used to hold the slab faces at transverse cracks which form at relatively close intervals, in intimate contact. Experience indicates that the minute transverse cracks cause no apparent detriment to the structural strength of the pavement and require no maintenance.

Several experimental projects of this type have been constructed in different parts of the country during the last few years. The first of the experimental continuously reinforced road test projects was constructed by Indiana in 1938 on US-40 near Stilesville, Indiana. This project contained a wide range of continuously reinforced sections on which detailed observations have been continued to date. In view of the interesting possibilities for continuously reinforced concrete pavements indicated by the Indiana project, the Illinois Division of Highways constructed a similar project in 1947 composed of eight long sections.[39]

In 1947, the New Jersey State Highway Department designed and constructed two approximately one-mile sections of continuously reinforced pavement. In May, 1949, the California Division of Highways planned and constructed a similar project. In 1950, the Texas Highway Department constructed portions of the Fort Worth north-south and east-west freeways with continuously

reinforced concrete. The Texas project was built for service as a preferred method of construction to serve heavy traffic with a minimum of interruption for maintenance and repairs.(39)

Pennsylvania has constructed two continuously reinforced projects—one on Route 111 near North York, Pennsylvania in which approximately 11,580 feet of pavement were continuously reinforced. A second project was constructed on Route 22 near Hamburg, Pennsylvania, in which approximately 10,800 feet of pavement were continuously reinforced. The York project was constructed in October, 1956 and the Hamburg project was placed in the spring of 1957. The difference in construction time was purposely arranged in order to distinguish between the behavior of the two pavements with respect to climatic conditions.(40)

Bituminous Overlays

The rapid breakdown of the older concrete pavements under postwar traffic started highway engineers looking for suitable and economical resurfacing methods. In 1952, North Carolina constructed a road test project 2.8 miles in length for the purpose of studying various types of bituminous surface treatments for overlay pavement on old portland cement concrete.(41)

Experimental Road Tests Comparing Flexible and Rigid Pavements

An important issue facing many highway administrators in recent years has been what type of materials to use for construction. Should they use portland cement concrete or bituminous concrete on their principal highways?

In the interest of the people of their respective States, the legislatures of Indiana and Oklahoma have by resolution instructed their respective highway commissions to construct experimental road tests in which both types of materials are to be included for test under identical circumstances.

The stated purpose in each case for these road tests is to determine: 1) durability, 2) lasting qualities under heavy truck and auto traffic, and 3) relative costs of initial application and subsequent maintenance. A brief description of each project follows.

The Indiana project was constructed on US-131, 1.8 miles north of Columbus. All pavement was placed during the 1953 construction season. Final section was opened to traffic on December 11, 1953.(42)

The Oklahoma project was started in 1953 and finished in 1954. It is located on US-66 and 77, about three miles east of Edmore, Oklahoma. It is a four-lane divided highway facility, approximately four miles in length. The asphaltic concrete and the portland cement concrete surfaces were arranged so that both types would rest on the same soil materials and be subjected to the same frequency and intensity of wheel loads.(43)

Both the Portland Cement Association and the Asphalt Institute were asked to suggest recommendations for the design and construction of their respective materials with the stipulation that if their recommendations met with the approval of the Highway Departments, they would be incorporated in the contract. Both projects are well designed and well built with an intensive test program following throughout construction. These projects should accomplish the original intent of evaluating the characteristics of the two pavement types.

Reflection Cracking in Bituminous Resurfacing

Two types of road tests have been performed for the purpose of controlling reflection cracking in bituminous concrete resurfacing over old concrete pavement. The Massachusetts Department of Public Works, in cooperation with the Massachusetts Institute of Technology, constructed test road projects in 1952 and 1953 using different types of bituminous concrete mixtures and various treatments of the joints prior to covering them with the resurfacing material. The bituminous concrete in certain instances contained mixtures of rubber additives.(44) Road tests to study the use of meshed reinforcement in bituminous concrete overlay to reduce cracking of the surfacing resulting from the reflection of the random cracking in the old pavement, were constructed by the Minnesota Highway Department in 1953. Other test projects of a similar nature are described in the literature.(45)

Bituminous Concrete Investigations

In 1952, the Kansas State Highway Department and the Applied Mechanics Department of Kansas State College started a cooperative study to investigate the behavior of hot mix asphalt concrete under the action of weather and traffic. The investigation includes the construction of a series of road test sections on designated highways subjected to heavy traffic, for observation and correlation with parallel laboratory research. This work is still in progress.(46)

Maryland Road Test One-MD

In June, 1949 at a meeting in Denver, Colorado, the Governors' Conference requested the Council of State Governments to study and report upon the matter of reasonable and uniform standards of motor vehicle maximum size and weight limitations. At the call of the Governor of Ohio, and co-sponsored by the Council, highway officials from 14 midwestern and eastern states conferred at Columbus, Ohio on December 5 and 6, 1949, to consider the size and weight problem as a matter of inter-regional concern. At this conference, it became apparent that an objective determination of the effects of axle loads of various magnitudes would afford the only possibility of eventual agreement of the entire membership on the important question of axle load limitations.

The conference formed itself into the Inter-Regional Council on Highway Transportation and appointed a Committee on Test Roads. This special Committee met in Baltimore, Maryland on January 9 and 10, 1950 to inspect a test road location proposed by representatives of the Maryland State Road Commission. After visiting the site of the proposed test road, the committee decided that the project, identified as Road Test One-MD, was feasible and recommended that tests be conducted at the joint expense of the participating State Highway Departments, the District of Columbia, and the Bureau of Public Roads, with the Highway Research Board responsible for the direction of the project. Trucks and fuel were furnished by Industry. Thus, the Maryland Road Test project was born.

The tests were conducted on a 1.1-mile section of existing concrete pavement on U. S. Route 301 near LaPlata, Maryland. The principal object of the test was to determine the relative effects on a particular concrete pavement of four different axle loadings on two vehicle types. For six months, the pavement was subjected to continuous, round-the-clock, 7-day week traffic

of single rear-axle trucks, two loaded to 18,000 and two loaded to 22,400 pounds per axle, and tandem rear-axle trucks, two carrying 32,000 and two loaded to 44,800 pounds per tandem.

It is of interest to note that this road test project was the first controlled traffic test to be made on concrete pavement since the Bates and Pittsburgh Road Tests of 1921 and 1922. The Maryland project was completed in 1951 and reported by the Highway Research Board in 1952, Special Report No. 4.

The AASHO Road Test Program

In 1950, the American Association of State Highway Officials completed plans for a series of regional accelerated, controlled traffic road tests. The purpose was to determine the effect of specific axle loads frequently applied at known speeds on existing representative pavements. The data from these tests would be used for policy determination of legal limits of load. The Western Association and the Southeastern Association each were to undertake a test of flexible type pavement, and the Mississippi Valley Conference was to conduct a test of rigid type pavement. The responsibility for the construction, operation and administration of these test projects was vested in the Highway Research Board.

The WASHO Road Test.—The WASHO Road Test project was inaugurated by the Western Association of State Highway Officials in 1950 as part of the AASHO Road Test Program. In contrast to the Maryland Road Test, the WASHO project was constructed entirely of bituminous concrete.

The road test was built on a future location of U. S. Route 191 near Malad, Idaho. This location was selected as representing climate and soil conditions in the Western region comprising the participating States.

The project, which was started in 1952 and completed in 1953, consisted of two identical loops, each with 1,900-foot tangents with test sections ranging from 6 to 22 inches total thickness. Test traffic was similar to that of the Maryland project in that one loop was subjected to single axle loads of 18,000 and 22,400 pounds; the heavier axle loads to operate on the outside lanes. The second loop was tested under tandem axle loadings of 32,000 and 40,000 pounds; the heavier loads, again, operating on the outside lanes. There were about two truck applications per 2.5 minutes, making about 1,600 axle repetitions per 20-hour test period. It was intended to study the behavior of flexible pavement under repetitive loads in the manner of the Maryland project, with the view of developing similar information for use in flexible pavement design. Equipment and fuel were furnished by segments of industry. Final reports were published by the Highway Research Board in 1954-55.(47)

The AASHO Road Test.—When the Mississippi Valley Conference met in 1951 to plan their road test, there was evidence of support for a road test of expanded scope to include new rigid and flexible pavements, with industry, state, and governmental cooperation. A new method of appraising load effect by determining the road cost of accommodation was advanced and economic measure of truck operation and highway requirements would supplement physical record. As a result of long planning, the AASHO Road Test became a reality in 1955.

The specific objectives of the AASHO Road Test are:

1. To determine the significant relationships between the number of repetitions of specified axle loads of different magnitude and arrangement,

and the performance of different thicknesses of uniformly designed and constructed asphaltic concrete, plain portland cement concrete, and reinforced portland cement concrete surfaces on different thicknesses of base and sub-base when on a basement soil of known characteristics.

2. To determine the significant effects of specific vehicle axle loads and gross vehicle loads when applied at known frequency on bridges of known design and characteristics. The bridges will include steel "I" beam design, conventional reinforced concrete design, and prestressed concrete design.
3. To make special studies dealing with such subjects as paved shoulders, base types, pavement fatigue, tire size and pressures, and heavy military vehicles, and to correlate the findings of these special studies with the results of basic research.
4. To provide a record of the type and extent of effort and materials required to keep each of the test sections or portions thereof in a satisfactory condition until discontinued for test purposes.
5. To develop instrumentation, test procedures, data, charts, graphs and formulas which will reflect the capabilities of the various test sections and which will be helpful in future highway design and in determining the most promising areas for future highway research.

The AASHO Road Test project is part of an eight-mile relocation of US-6 near Ottawa, Illinois. It will consist of four loops, each approximately 7,600 feet in length and one loop 5,000 feet in length. There is an additional auxiliary loop for special studies approximately 2,200 feet in length located adjacent to one of the main loops. Half of the test pavement will be of rigid type construction and the other half will be of flexible type. Sixteen test bridges of conventional types are also included for testing under the heaviest axle loads.

Test vehicles will be loaded to provide single axle loads of 2,000, 6,000, 12,000, 18,000, 22,400 and 30,000 pounds, and on tandem axle loads of 24,000, 32,000, 40,000 and 48,000 pounds. The vehicles will be driven at 30 mph., 18 hours a day, and 6 days a week for a period of two years.

Each loop will have two test lanes with concrete pavement on one tangent and bituminous concrete on the other tangent of the loop. Portland cement concrete slabs will vary from 2-1/2 to 12-1/2 inches in thickness. Sub-base thicknesses underneath the slabs will vary from zero to 9 inches. The flexible pavement will vary from 1 to 6 inches in thickness, laid on various combinations of base and sub-base thicknesses ranging from zero to 25 inches. Many other experimental factors are also included for study.

The experimental part of the project is designed on the basis of the most modern statistical experiment design techniques in order that a maximum of effective information may be obtained from a minimum number of test sections.

It is expected that the project will be completed and ready for test traffic in the Fall of 1958. Results from the testing work will probably not be ready for reporting before the Spring of 1961.

This project is being financed cooperatively by State Highway Departments, the Bureau of Public Roads, Department of Defense, Automobile Manufacturers' Association, and the Petroleum Industry.[48,49]

SUMMARY

The highways of the future offer many problems. In solving these problems, the highway engineer will always be hampered by the lack of determined facts. Therefore, the encouragement of highway research is a vital part of the engineering of future highways.

Trial roads and long range experimental road tests remain a popular method of obtaining engineering facts upon which to base local design and construction policies. They also provide useful technical information for the general knowledge.

In recent years, controlled traffic road tests have appeared for the purpose of obtaining much needed engineering facts under accelerated conditions. It is intended that these facts be used with other data to solve urgent problems associated more directly with the national transport situation.

The general upward trend in interest and expenditures for highway research by different agencies is a healthy sign. This would indicate that the country is slowly reaching a stage of unity and maturity. The States, the Federal Government and the Transport Industry in a sense are abandoning their individual interests and acting collectively to solve highway transport problems. Together, they can inaugurate a new era of research and highway progress.

ACKNOWLEDGMENT

This historical review of road tests was suggested by Mr. William A. McWilliams, former chairman of the Highway Transport Committee of the American Association of State Highway Officials which was intimately associated with the planning of the comprehensive AASHO Road Test now under construction near Ottawa, Illinois.

It was his belief that such a work at this time would provide both information and understanding of road tests, and by learning how far we have come in the past, we should be in a better position to chart a highway research course for the future.

The materials in the paper have been arranged chronologically. Time or occasion did not warrant an exhaustive search of the literature or of other sources. Thus, it is recognized that there may be omissions of road tests not adequately covered in the technical literature.

I take this opportunity to thank Donald Emerich, technical writer, Highway Research Laboratory, for his able assistance in collecting bibliographical material, and in editorial review.

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Journal of the
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CREATING A BETTER UNDERSTANDING OF TRAFFIC ENGINEERING[a]

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(Proc. Paper 1797)

ABSTRACT

The ever increasing use of private motor vehicles as our means of transportation has necessitated the engineering specialization presently known as Traffic Engineering. Traffic Engineering is that phase of engineering which deals with the planning and geometric design of streets, highways and abutting lands, and with traffic operation thereon, as their use is related to the safe, convenient and economic transportation of persons and goods.

Unless one takes the time to reflect and look back to the era of several decades ago, he actually fails to realize how his mode of present day living is constantly being changed due to advances and discoveries occurring in engineering and other fields of technology.

Some of you may recall the efforts formerly required and the time consumed in traveling into town for your needed supplies—and those mud roads which first required repeated rests and watering for your horses, and later challenged every puff of your first automobile. When one compares our present mode of transportation involving millions of vehicles now traveling on our streets and highways in this country, with this former horse and buggy era, it is hard to realize that this transportation change actually has occurred within the last fifty years. The statistic books tell us that at the turn of the century there were only 8,000 motor vehicles in this country, whereas today almost sixty million vehicles are in operation. The 1957 motor vehicular registration is approximately one vehicle for every three persons. During the last thirty years this increased growth in vehicular traffic has been at a rate of 4% annually, which rate of growth has been predicted to continue for the next twenty years.

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a. Presented at the Highway Division Session of the ASCE, October 16, 1957.

1. Cons. Engr., Pittsburgh, Pa.

This change in means of travel has resulted in the development of large tracts of suburban land, and even farm lands, for residential and industrial use. During the years, as urban population expanded, many city dwellers built residences and moved to these newly developed suburban areas. Since mass transportation facilities could not economically extend their services to these scattered and sparsely settled areas, a private passenger vehicle became one of the first requisites for a suburbanite. As the growth of automobile traffic continued, the business districts of metropolitan cities found their old horse and buggy streets gradually being choked with trucks and passenger vehicles. When the congestion further increased, many shoppers either started to, or threatened to, avoid the business district. This brought the merchants clamoring to the elective officials for relief from this new situation.

Since the civil engineering departments of some of our universities were then teaching "Highway Construction and Transportation" as an undergraduate course, graduate students of civil engineering became the logical source for the knowledge to cope with this problem.

In 1924 the City of Pittsburgh was the first city in the country to recognize this as a full time need, and employed Mr. Burton W. Marsh as City Traffic Engineer. His functions were at first not clearly specific, but were evolved with experience in pioneering the application of engineering to city transportation needs. Shortly thereafter, other large cities either employed a young engineer or took one of their engineers from their Works Department to serve at least on a part time basis in the capacity of "traffic engineer" for their city. At this time only a very limited amount of specialized engineering data relating to highway traffic was available. The few traffic signals then in operation were primarily hand made for a particular installation. Signs were mostly locally made and varied widely as to size, shape and color. Street marking paint was ill-suited to street traffic conditions. Few instruments or devices were actually designed for traffic use.

Each of these engineers with their limited specialized knowledge on this subject carried on to the extent their limited budget permitted, whatever studies they thought would prove most helpful in coping with their traffic problem. They experimented with devices for traffic control at intersections, and for inter-relating such controls so that traffic might flow for a number of blocks without being stopped by signals at successive intersections. They studied traffic movements and volumes, speeds, delays and the effects which various turns had on traffic capacity. They made studies and observations of routes and speeds of mass transportation vehicles and the effect which loading and unloading of these vehicles had on traffic congestion. They were continually endeavoring to obtain essential data and information that could show them how to alleviate the congestion or remove the causes of accidents at various specific locations in their community. While these studies were proceeding, traffic volumes continued to increase, and the streets in the business sections were becoming more congested. Traffic accidents had now become one of the major causes of death and property loss in this country. The National Safety Council recognized this menace and in the late twenties, and as a part of their annual safety conference established a new organizational section on "Streets and Highways". These conferences brought together those City Traffic Engineers that were working on this problem and served as a clearing house, so that the various techniques and ideas that they had developed could be made available for the benefit of everybody.

In 1930 at one of these annual safety conferences, held in Pittsburgh, nineteen traffic engineers met in the then Wm. Penn Hotel for the purpose of formulating an organization so that technical information on traffic engineering could be stimulated and guided in a constructive engineering manner, and so that such information could be compiled and made available promptly to all the engineers in this field. Before this meeting adjourned the Institute of Traffic Engineers had been organized.

It might interest Members of the American Society of Civil Engineers to know that in the preliminary investigational work before the organization of the Institute of Traffic Engineers, an approach was made to the American Society of Civil Engineers regarding the idea of having this newly developing engineering specialty become organization-wise, a division or other unit of the American Society of Civil Engineers. This proposal was not received favorably, apparently due to the lack of realization on the part of various of the Members of the American Society of Civil Engineers of the potential growth and importance of this special engineering field.

With this impact of traffic growth, members of the American Society of Civil Engineers had their own many problems. Planning had to be intensified, highways and bridges had to be designed, and constructed, and little space or time was available at their meetings or in their publications to discuss the problem of traffic regulation and control. Further, it is imagined that back in the late twenties and early thirties, many of the civil engineers were so concerned with their own activities that the concept of traffic engineering did not receive their thought or attention. Some probably thought of traffic engineering in terms of safety, while others may have thought of it in terms of police activities, since it involved an element of control. Apparently, the principal misunderstanding was due to the fact that very few engineers actually knew what traffic engineering was. However, with an educational background of engineering, traffic engineers that pioneered in this field could not fail to recognize that the traffic control problem would only be solved by an engineering approach. They are now more than ever convinced, after many years of experience observing the improvements that can be achieved, that the complex traffic control problem is only going to be solved by the application of engineering techniques. Apparently a great many additional persons now agree, for already the Institute of Traffic Engineers has a membership of over 1,100, made up of hundreds of traffic engineers employed by cities and states, many by national organizations, a number of consulting engineers, a number of such specialists in foreign countries, college faculty members, etc.

To those who haven't thought much about the importance of operations engineering, let me cite two quick parallels:

1. In the railroad field, in the early days, most engineering was in reconnaissance, planning, design, and construction. Organizational charts showed the major importance of such activities. Look now at railroad organizational charts—and note how OPERATIONAL matters predominate. The railroads have long realized the tremendous importance of efficient and safe operations.
2. The assembly line in a motor vehicle manufacturing plant is a marvel of concept and clever design. Yet what good would all the physical equipment be WITHOUT EFFECTIVE OPERATIONS.

Those engineers who have devoted much of their lives to traffic engineering believe that the specialized training and experience necessary to thoroughly and efficiently perform traffic engineering service varies considerably

from the engineering services generally rendered in the category of civil engineering. But they readily recognize that in many instances the fields of traffic engineering and civil engineering are extremely closely related. This is particularly so in the planning field. This relationship has already been recognized in several of our larger universities. At present, graduate courses in traffic engineering are being offered to engineers at the Universities of Illinois and California, and Northwestern, Purdue and Yale Universities.

What is "Traffic Engineering"? The official definition as defined by the Institute of Traffic Engineers is as follows:

"Traffic Engineering is that phase of engineering which deals with the planning and geometric design of streets, highways, and abutting lands, and with traffic operation thereon, as their use is related to the safe, convenient and economic transportation of persons and goods."

In actual practice, the traffic engineer administers or performs a wide variety of functions. Among these are found the gathering and analysis of physical, economic, and operational facts pertaining to streets, highways, parking and transit, the planning incident to their proper location and operation, the design or re-design of the geometric characteristics relating to traffic, and the development and application of control devices and measures required for the efficient and safe regulation, warning and guidance of drivers and pedestrians.

He gathers, analyzes and acts upon traffic operations data of various kinds. He studies not only street and highway motor vehicle traffic but transit, and parking and loading. He has to consider the future, the likely development of the city, changes in transportation vehicles and in the whole pattern of urban and metropolitan development. He must consider present and future traffic volumes, routings, speeds, delays, accidents. He must analyze why certain intersections or streets or city layouts cause trouble and what can be done to remedy the trouble to the maximum practicable extent.

Because month after month and year after year, the traffic engineer must deal with all such matters, he is BOUND to acquire knowledge and concepts which can be highly useful in planning and design. With the experience gained through working with operational matters, the traffic engineer, if given the opportunity, can generally spot errors in design which, if not corrected, would later affect the operations of the completed facility. Detroit, San Diego and many other cities have found great merit in having the traffic engineer as part of the TEAM which develops future plans for the city and its essential transportation. In fact, in Chicago and in numerous other cities, the signature of the traffic engineer must appear on every street and highway transportation improvement plan before it becomes official. It's the operational aspects to which the traffic engineer naturally gives major attention.

Every person who enters upon the public ways—by private motor vehicle, mass transit, truck or afoot—is affected by the quality of the traffic engineer's performance. Transportation costs for practically everything that is used, eaten or worn are intimately associated with the problems that confront the traffic engineer. Unfortunately, the traffic engineer possesses the same characteristic as that of other engineers, in that he fails to make known to the public his many accomplishments. This is of particular importance since the efforts of the traffic engineers controls the action of all people every day of their lives. The direction and ease in which they travel daily, and whether they reach their desired destination without being involved in an accident is under the direct surveillance of the traffic engineer.

Probably more so than with any other of the engineering professions, the traffic engineer's efforts are under constant scrutiny of the whole public. Generally, unless his efforts achieve significant visual improvement in relief from traffic congestion or accident reduction, he is constantly besieged with the criticism of motorists. Frequently, his efforts can achieve noticeable improvements in traffic relief at a very small cost. Sometimes his efforts cannot achieve these noticeable improvements without involving an enormous cost, as the basic cause is one of faulty design of the street or highway when it was first constructed. Unfortunately, the traffic engineer frequently finds himself in the position of having to point out these inadequacies of early design which sometimes makes him very unpopular with the design and construction engineers of the street or highway department.

Last year, in this country, there was an economic loss of 4-3/4 billion dollars from traffic accidents alone. This monetary loss in one year could have been used to build a half million new American homes; and is equal to the annual net income of more than one hundred of the nation's biggest Corporations. A paper presented by the speaker in 1936 before the City Planning Section of the American Society of Civil Engineers pointed out that at the then current rate of $.40 per hour, the cost of delay to the citizens of Pittsburgh during only the peak hours of one day was equal to $10,000.00. If this figure were adjusted for today's minimum hourly wage of $1.00, and then multiplied by 300 days per year, and then applied to include all the cities in this country, the billions of economic waste annually due to delays and congestion would be staggering.

It is in this field of elimination of economic waste, by the achieving of efficient, orderly, convenient and safe highway transportation, that the traffic engineer concentrates his effort. He is not concerned with the specific structural characteristics of the streets and highways and the many other engineering details other than their geometric design and how they affect the movement of traffic.

He is not concerned as to whether a bridge is of a suspension type, cantilever or open deck design, or whether steel or concrete is used as its principal structural material. He is vitally concerned about its number of lanes and their width, the radii and sight distances on its approaches, the adequacy of the street lighting and sidewalks, the design of its medial strip and curb guards, and its type of pavement only so far as the safe and convenient operation of the vehicle is concerned. In other words, so far as the design of the bridge is concerned, the traffic engineer is interested in only one thing—the safe, economical, efficient movement of people and goods. But even before it has been decided to design the bridge, the traffic engineer along with the planning engineer should be concerned as to the proper general location of the bridge as determined by current origin and destination studies and land use analyses so that the completed structure will afford the greatest service to not only the local inhabitants but also to motorists living both in the near vicinity and at distant areas who would have occasion to use the facility.

These details of the bridge and its approaches which concern the traffic engineer, generally represent only a minor portion of the over-all engineering design work and the total cost of the project. However, since these details will determine the manner in which motorists will travel thereon when the project is completed, an engineer conversant with the knowledge of safe and efficient operation of traffic should determine as to such matters, or at least collaborate thereon, if the ultimate capacity and efficiency are to be obtained from the project when it is completed.

The speaker has used a bridge and its approaches only as an illustration to show those elements of design on which the knowledge of a traffic engineer should be used. Illustration of intersection design, expressways and highways, etc., could have been used to indicate the same need of cooperation between the traffic engineer and the designing or planning engineer. Unfortunately, in many instances during the past years, this need for traffic engineering knowledge has not been recognized or at least willingly accepted by some designing and planning engineers. Such lack of cooperation involves a considerable risk that the completed project will fail to provide motorists with a safe and efficient facility.

This nation has just embarked on an enormous highway construction program involving many billions of dollars. Half of this money will be spent in the urban areas where large concentration of vehicular traffic is involved. The complete cooperation of all the agencies in these urban areas and the use of all the technical knowledge available, both in design and operation, is of utmost importance if we are to provide this nation with the highway facilities essential to handle its future traffic volumes.

Better understanding of traffic engineering is important these days. The general public needs to be better informed on how traffic engineering gives them better and safer operational conditions as they drive or walk. This better public understanding will be achieved by a public information program—and there are a number of groups working on that, including the National Safety Council, Automotive Safety Foundation, American Automobile Association, Association of Casualty & Surety Foundation, American Automobile Association, Association of Casualty & Surety Companies, President's Committee for Traffic Safety, National Highway Users Conference.

But equally important is achieving better understanding among fellow engineers, planners, other professional groups dealing with highway transportation.

How is this to be achieved? Discussions at meetings such as this will help. But much more needs to be done. Many more opportunities for interchange of information, ideas, views, problems must be provided. May I recommend that one or more traffic engineering speakers be included on future highway division sessions—giving special attention as to how a professional with broad experience in traffic engineering can benefit the highway engineer.

More joint activities should be carried on. One project which this highway division might institute would be a joint analysis, by experienced educators, teaching traffic operational subjects and those teaching civil engineering, so that jointly they could recommend a more complete course of study for Highway Engineering.

The planning division of the American Society of Civil Engineers and traffic engineering leaders would benefit by a workshop or a series of workshops, on the relation of over-all planning to highway and traffic development in metropolitan areas.

The structural engineers, architects and traffic engineers should set up a mechanism for swapping viewpoints on new buildings and for parking and loading in relation thereto.

The United States Steel Corporation has just completed "Jonah and the Highway"—a 27-minute film to help improve understanding of the job of the highway engineer. A film of that sort, if well done, would help greatly in creating better understanding of traffic engineering.

Traffic engineering accomplishments—and there are lots of them—need to be MUCH more effectively brought to the attention of the public, as well as to other professional groups.

There is no question that MUCH remains to be done in creating a better understanding of traffic engineering, or of the NEED for doing so, since anything like the estimated growth of traffic will make tremendously more important the securing of maximum efficiency, orderliness, convenience and safe use of streets, highways, parking facilities, etc.

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THE AASHO ROAD TEST—A PROGRESS REPORT[a]

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(Proc. Paper 1798)

The AASHO Road Test at Ottawa, Illinois, is the largest highway research project ever undertaken. It is sponsored by the American Association of State Highway Officials and administered by the Highway Research Board of the National Academy of Sciences—National Research Council. This paper outlines objectives and purposes, administrative procedures, financing, and progress of the construction of the test facility.

In a paper on the AASHO Road Test presented before this society at its annual convention in Pittsburgh, Pennsylvania, in October of 1956, the writer and Mr. Fred Burggraf, director of the Highway Research Board, spoke of the "revolution in transportation" that had occurred in the first half of the Twentieth Century.

This revolution continues unabated. Perhaps it escapes our notice from month to month and year to year, but its cumulative effect may be as startling over the last half of the century as it was over the first half. People today look back with amazement on what has occurred in the highway transportation field since the days of the first "gas buggies". In the year 2000 people will look back with equal amazement on what will have occurred since 1950; or, more likely, since 1956.

The year 1956 was a great milestone in the highway industry. In setting up the 15-year program to provide more than 40,000 miles of modern freeways, the nation proved that it fully recognized that the highway is now, and will be for many years, its most important transportation facility. The people decided through their representatives in Congress that it was worthwhile to spend billions of dollars to modernize this system.

As recent reports have shown, the huge program of building the National System of Interstate and Defense Highways is well under way. Already the impact of this program is being felt from coast to coast and border to border; and, as it progresses, its effects will reach into every village, town and city—yes, even into every factory, store, office and home.

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a. Presented at the ASCE Convention in Feb., 1958 in Chicago, Illinois.

1. Proj. Dir., AASHO Road Test, Chicago, Ill.

The Interstate program, plus the construction and reconstruction of other roads and streets, will mean an expenditure of over 100-billion dollars in the next 15 years. This is nearly double the amount spent by all units of government on highways and streets in the 15 years from 1941 to 1955 inclusive. Obviously, the construction of these thousands of miles of modern highways means many problems for highway administrators and engineers. Obviously, too, it demands that highway officials continue to improve and expand their knowledge of their profession through research.

This is an age of research. There is scarcely an existing field of endeavor where some type of research is not being carried on. This unceasing search for new facts, new ideas, and new theories has been a large factor in the progress and prosperity of the nation; and, in the present state of world affairs, the research efforts of scientists and engineers become even more important.

In the highway field research has been a major activity for many years, increasing as the network of roads expanded and the number of motor vehicles grew. A significant point in the history of highway research was the formation of the Highway Research Board in 1920 in order to encourage research and provide a national clearing house for dissemination of information. This organization is a unit of the Division of Engineering and Industrial Research of the National Academy of Sciences—National Research Council. It is now administering and directing the largest highway research project ever undertaken.

This project is known as the AASHO Road Test, for the sponsoring organization, the American Association of State Highway Officials. The facilities for the test are under construction at Ottawa, Illinois, about 80 miles southwest of Chicago. Six test loops are being built with 836 separate sections of pavement of widely-varied thicknesses. Beginning in the late summer of this year, vehicles with axle loads ranging from 2000 to 48,000 lbs. will be operated on these pavements. This traffic will run 18 hours a day, six days a week for two years; and millions of pieces of data on the behavior of the pavements will be collected.

This huge experiment has specific objectives as well as several broad, general purposes. Its specific objectives are:

1. To determine the significant relationships between the number of repetitions of specified axle-loads of different magnitude and arrangement and the performance of different thicknesses of uniformly designed and constructed asphaltic concrete, plain portland cement concrete, and reinforced portland cement concrete surfaces on different thicknesses of bases and subbases when on a basement soil of known characteristics.
2. To determine the significant effects of specified vehicle axle-loads and gross vehicle loads when applied at known frequency on bridges of known design and characteristics. The bridges will include steel I-beam design, conventional reinforced concrete design, and prestressed concrete design.
3. To make special studies dealing with such subjects as paved shoulders, base types, pavement fatigue, tire size and pressures, and heavy military vehicles, and to correlate the findings of these special studies with the results of the basic research.
4. To provide a record of the type and extent of effort and materials required to keep each of the test sections or portions thereof in a satisfactory condition until discontinued for test purposes.

5. To develop instrumentation, test procedures, data, charts, graphs, and formulas, which will reflect the capabilities of the various test sections, and which will be helpful in future highway design, in the evaluation of the load-carrying capabilities of existing highways and in determining the most promising areas for further highway research.

Of course, the findings of the AASHO Road Test, when combined with the results of other studies, will have even wider applications.

They are expected to be useful not only to highway administrators and engineers, but also to legislative bodies and to motor vehicle manufacturers.

The Congress of the United States has specifically requested that data from the test be included in studies now under way to determine the "maximum desirable dimensions and weights of vehicles to be operated on the Federal-Aid Highway Systems, including the Interstate System . . ." and to determine "an equitable distribution of the tax burden among the various classes of persons using the Federal-Aid Highways or otherwise deriving benefits from such highways."

It was with these objectives and purposes in mind that the Highway Research Board accepted the responsibility of administering the AASHO Road Test. However, it should be noted that the Highway Research Board's function ends in making available the data from the test. What is done with this data will be up to others.

The Board took over administration of the project in 1955 and began to organize for the task ahead. Fortunately, it has been able to assemble a cooperative and understanding staff team of engineers, scientists and administrators with national reputations as experts in their respective fields. This staff has spent many months on the detailed planning necessary before the testing phase of the project can begin. It has, with the aid of consulting engineers, conceived and developed the instruments necessary to measure and record the effects of the traffic on the test pavements; and it has supervised, cooperatively with the Illinois Division of Highways, the extremely rigid control of materials and construction in order to assure test pavements which are uniform in all respects except thickness.

The staff has not accomplished its tasks without the advice and guidance of experts in many fields. A 34-member National Advisory Committee for the project is made up of men from state highway departments, the Bureau of Public Roads, the Department of the Army, several universities, industrial associations, and such groups as the American Automobile Association, the Automotive Safety Foundation, and the National Highway Users Conference.

Working through the National Advisory Committee are four regional advisory committees made up of representatives of each state and territorial highway department. And, for advice in specific areas of knowledge, there are eight technical panels made up of men experienced in such fields as statistics, instrumentation, materials and construction, soils, bridges, maintenance, vehicles and public information. All advisory committees and panels serve without compensation.

Not only does the AASHO Road Test draw advice and guidance from all parts of the country, it gets its financial support on a nationwide basis. The cost of the project is being shared by the states and District of Columbia, the territories of Hawaii and Puerto Rico, the Bureau of Public Roads, the Automobile Manufacturers Association, and the American Petroleum Institute. The Department of Defense is cooperating and assisting the project by furnishing Army Transportation Corps troops to drive the test vehicles.

Just prior to the beginning of construction of the project, it was estimated that it would cost about 12-million dollars. However, it became evident during 1956 that additional money would be needed if the project was to accomplish its assigned tasks. There were several reasons for this.

First, to obtain information required by the Federal Highway Act of 1956, it was necessary to add another test loop to the project and to enlarge an already-planned loop for special studies. This Act also calls for a report to the Congress by March 1959, making it necessary to plan for a high degree of automatic handling of data and high-speed reduction and analysis.

Secondly, in order for the highway industry to get the greatest value for the funds invested in the project, many refinements were made. The geometric design was improved. The experiment design was strengthened and includes more test sections than originally planned. Materials specifications and construction control were tightened to further insure uniformity in construction of the test facility.

In the meantime, of course, all costs—materials, wages, equipment and services—have been rising; and, as the project grew, so did the cost of all elements entering into the project.

The several states, the District of Columbia, the territories of Hawaii and Puerto Rico, the Bureau of Public Roads, the Department of Defense, and the industry groups are all to be complimented for recognizing the need and providing additional money for the project. During 1957 the member states and territories of the American Association of State Highway Officials agreed to increase their contribution by $3,500,000. The Bureau of Public Roads has increased its contribution by $5,447,200. In the industry category, the Automobile Manufacturers Association, which is contributing $1,300,000 was joined by the American Petroleum Institute with a contribution of $875,000.

The estimated total cost of the AASHO Road Test is now $21,703,300. While this figure may sound large in comparison with past expenditure for highway research, it is minute when compared to the more than $100-billion the nation will spend on roads and streets in the next 15 years. If the cost of the AASHO Road Test— a five-year project—is related to five years of expenditures of the road program, it amounts to less than a tenth of one per cent. It is important to note, too, that $4,042,000 of the total cost of the project represents the construction of the permanent Illinois-Federal Aid facility. Thus, the actual cost of the research project is $17,661,300.

Construction at the AASHO Road Test began in the late summer of 1956. During this phase of the project, the State of Illinois is, of course, playing a major role. Its Division of Highways has handled acquisition of right-of-way, preparation of plans, and through its normal contractual arrangements, construction of the test loops.

Of course the site selected for the test facility, in addition to being an area where soil and climate are typical of wide areas of the country, is a future location for an east-west highway in the Interstate System. When testing of the pavements is completed, they will revert to the state and be rehabilitated before being incorporated into the Interstate System.

Construction of the earth embankments for the test loops began in late August. Between this time and mid-November, more than a million-and-a-quarter cubic yards of earth were moved. About half of this was placed in the upper three feet of the embankments under controls more strict than any ever attempted in large-scale highway construction. These controls were aimed at

producing an embankment which was highly uniform in support strength and which can then be discounted as a variable in the experiment.

A large concentration of manpower and equipment was necessary to carry out the grading work in the limited time available. At the peak of operations the contractors had on the job more than 200 pieces of construction equipment valued at more than $5-million.

The embankments were constructed from a fine-grained clay soil obtained from three borrow pits adjacent to the project. Large earth movers placed the material, and it was bladed into six-inch loose lifts.

The material was then processed by teams of rotary speed mixers which pulverized the soil and added the proper amount of water to bring it to the required moisture content.

Following this, the material was compacted by pneumatic-tired compactors loaded to 15 tons and operating in a carefully-controlled pattern. Specifications called for the compacted four-inch lift to have a density between 95 and 100 per cent of standard maximum and a moisture content between plus or minus two per cent of optimum.

All of this work was carried out in construction blocks 700 to 800 feet long with transition areas at each end. All heavy equipment was required to cross over the embankment or turn around in these transition areas. These areas, where the density was not carefully controlled, will not be a part of the test.

This quality control of construction necessitated many laboratory and field tests. During compaction of the embankment in the fall of 1956 and spring of 1957, the materials laboratory performed about 50,000 density and moisture content tests.

The mainstay of this testing operation was a high-speed drying oven designed by the staff. It uses an endless chain to carry soil samples under a battery of infra-red lamps. This oven will dry a soil sample in 23 minutes, while a conventional oven might take several hours.

The materials laboratory handled this program on an assembly-line basis. Two-way radio was a great help in dispatching trucks to pick up samples in the field and in reporting test results back to the field. The laboratory had only 90 minutes from the completion of rolling a block lift to obtain samples, get them to the laboratory, run all tests, analyze results, and report back to the field.

During 1956 construction of the earth embankments was about 95 per cent completed. Thus, the first task in the spring of 1957 was completion of the earthwork. It was anticipated that this work would get under way in May and be speedily completed. However, adverse weather interfered with these plans. During the months of May and June the contractors were able to work only a limited number of days, and work on the embankments was extended into July.

Meanwhile, the Illinois Division of Highways advertised for bids on May 17 for the paving of the test loops and connecting roadways. A single bid was received in the amount of $6,622,514. This bid exceeded funds available for this portion of the work and was rejected by the Illinois Division of Highways with the concurrence of the Bureau of Public Roads.

This development, coupled with the delay caused by bad weather, made it impossible to complete construction of the test facility in 1957 as had been originally planned. The project schedule was pushed back some ten months.

In retrospect this unavoidable delay appears most favorable. It has given the staff additional time to plan, develop and improve upon the instrumentation and to pursue certain studies which had been put aside because of lack of time

under the previous schedule. These additional efforts will make the test results even more sound and unassailable.

This change in the project schedule did not halt construction work during the 1957 season. Under the grading contract work went ahead on the subgrading of the completed embankments. This operation employed a subgrading machine operating on forms to trim the earth to precise grade. The tolerance was plus or minus one-eighth inch.

The grading contract also involved placement of the first layer of sand-gravel subbase material. An unusual operation was devised to produce this material. Previously washed and screened material was run through a batch plant where the exact amount of fines was added. The material was then mixed batch-by-batch in a paving machine.

About 130,000 tons of this material was produced and placed on the embankments. This necessitated another unusual operation. Specifications prohibited heavy equipment from operating on the center 24 feet of the embankment where paving will be placed in order not to spoil the uniform compaction. This forced the contractor to operate loaded trucks on the shoulder portion of the embankment. The subbase material was dumped into a conveyor-loader, carried across the subgrade to a spreader. The spreader was pushed by a tractor which operated on the material it was spreading.

While this work was under way, the Illinois Division of Highways called for new bids on paving the test loops. Bids were received in August and the contract awarded in late August to the S. J. Groves and Sons Company at a price of $5,690,000. This brought the total estimated cost of construction, including rehabilitation, engineering and contingencies to $12,526,700.

The paving contractor immediately began to move in and set up equipment, and the construction work went on without interruption. Batching and mixing plants for portland cement concrete and asphaltic concrete were set up and placed in operation. Paving of the test loop turnarounds was begun, and the construction of pilot test sections of rigid and flexible pavement was started.

The pilot test sections permit the engineers to evaluate various construction methods and equipment in advance of paving the actual test sections next summer. In the rigid pavement pilot test, for example, the contractor poured 2-1/2, 3-1/2 and 5-inch thick slabs of reinforced portland cement concrete in order to provide an opportunity to experiment with methods of installing wire mesh reinforcing in unusually thin slabs.

Also constructed were short sections of rigid and flexible pavement in which many instruments have been installed just as they will be in the actual test sections. This has allowed the development of techniques for installing these devices and collection of some preliminary data on their performance in the field.

Other construction completed during 1957 included 12 of the 16 test bridge spans which are in four locations in two of the main test loops. These bridges are simple 50-foot spans, consisting of three beams and a concrete slab for a riding surface. In eight of the bridges the beams are steel I-sections, in four they are conventional reinforced concrete, and in four they are prestressed concrete.

Four overpass bridges which carry local roads over the main test loops were completed and opened to traffic during 1957. Frontage roads were graveled and will be surface treated next spring. Considerable quantities of materials for the paving operations have been produced and stockpiled.

Rapid progress was also made in the construction of buildings on the project. The Administration and Laboratory Building was occupied by the staff in January of 1957. In March construction was begun on a 6000-square-foot vehicle maintenance building which was essentially completed by mid-summer. In September construction was started on five buildings in a housing-administrative-recreation area for the Army Transportation Corps troops who will drive test vehicles. These latter buildings are scheduled for completion in June, 1958.

In addition to the construction work, of course, the multitude of detailed planning and scheduling, development of instruments, and testing of materials goes constantly onward. Another major task of the staff has been the spreading of the AASHO Road Test story across the nation. Articles on various phases of the project have appeared in the leading engineering and technical publications. Staff members have spoken before many groups of engineers and highway administrators, road schools, and, of course, to the general public. Illustrated brochures on the project have been published and widely distributed, and newspaper releases and news letters have been disseminated. In addition, hundreds of persons have visited the project, toured the field construction and viewed exhibits of instruments and measuring devices in the Administration Building.

By 1959 the test traffic will have been operating over the pavements for several months, and the project will be well into the collection of important data—data which is expected to influence the design and construction of highways for many years to come. For this is the goal of the AASHO Road Test—sound, logical and unassailable facts and figures; data which will be meaningful and helpful to all highway administrators and engineers. This will be data which will fulfill the specific objectives of the project and be useful to others in accomplishing their aims in the overall effort to provide better and safer highways for a growing and progressive nation.

Paper 1799 October, 1958 HW 3

Journal of the

HIGHWAY DIVISION

Proceedings of the American Society of Civil Engineers

REINFORCEMENT IN CONTINUOUS CONCRETE PAVEMENTS

Vedat A. Yerlici[1]
(Proc. Paper 1799)

SYNOPSIS

The purpose of this paper is to present a straight forward reinforcement design procedure for continuously reinforced concrete highway pavements. Upon selection of a maximum permissible crack width, a section of the slab between cracks is analyzed to satisfy the static equilibrium and the assumed geometric condition that the slab length does not change. Formulas are derived for necessary crack spacing and optimum steel area and perimeter.

INTRODUCTION

The function of the continuous reinforcing steel in a concrete pavement is to maintain reasonable continuity in the slab by distributing the effects of concrete contraction due to shrinkage and temperature drop. The effect of the steel in helping to carry the wheel loads over the pavement is considered negligible.

An examination of the behavior of several experimental continuously reinforced concrete highway pavements indicates that the continuous slab does not significantly change in length due to shrinkage and temperature drop, except at the end portions where it is free to move.(1) Therefore, it is valid to analyze the interior portions of the slab as fixed at both ends. When a strip of concrete pavement restrained at its ends tries to contract appreciably, it cracks because concrete lacks the ductility to maintain its original length. If only a few cracks develop, each is relatively wide, seriously disrupting the

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continuity of the pavement and permitting rapid deterioration at the cracks. Continuity is more nearly achieved if the cracks which develop are closely spaced, and therefore as narrow as possible. The solution then, is to place continuous reinforcing steel longitudinally into the pavement, in such a way, and of such an amount, that cracks which will develop will be closely spaced, but so narrow that the granular interlock of the cracked faces will be preserved to the greatest possible degree.(2)

A sound approach is to establish, first, an acceptable crack width, that will not permit deterioration, and then, secondly, to determine the spacing of the cracks to insure that the permissible crack width will not be exceeded even under the most severe conditions.(3) Narrow, closely spaced cracks, assure the greatest durability, and a satisfactory continuity essential to good behavior under heavy traffic during all seasons of the year. Based on the premise of a restrained slab with a permissible crack width, the spacing of the cracks and the amount of steel can be found.

Necessary Crack Spacing

Once the maximum permissible crack width is established, the spacing necessary to insure that this width will not be exceeded can be computed.

Δ = maximum permissible crack width

L = maximum possible crack spacing in the pavement

a = sum of the length of broken bond at both ends

ϵ_{sh} = strain in concrete caused by shrinkage

f'_c = ultimate tensile stress of concrete

E_c = modulus of elasticity of concrete

α = coefficient of thermal expansion of concrete and steel

T = maximum drop in temperature

In Fig. 1 a length of pavement "2L" has been shown such that cracks of a permissible width "Δ" develop at each end. The mid-part of the section is considered stationary.

$$\epsilon_{sh} L + \alpha T L = \Delta + \frac{1/2 f'_c}{E_c} (L - a) \tag{1}$$

$$L = \frac{\Delta - \dfrac{1/2\ f'_c a}{E_c}}{\epsilon_{sh} + \alpha T - \dfrac{1/2\ f'_c}{E_c}} \tag{2}$$

$$L = \frac{\Delta}{\epsilon_{sh} + \alpha T - \dfrac{1/2 f'_c}{E_c}} \tag{3}$$

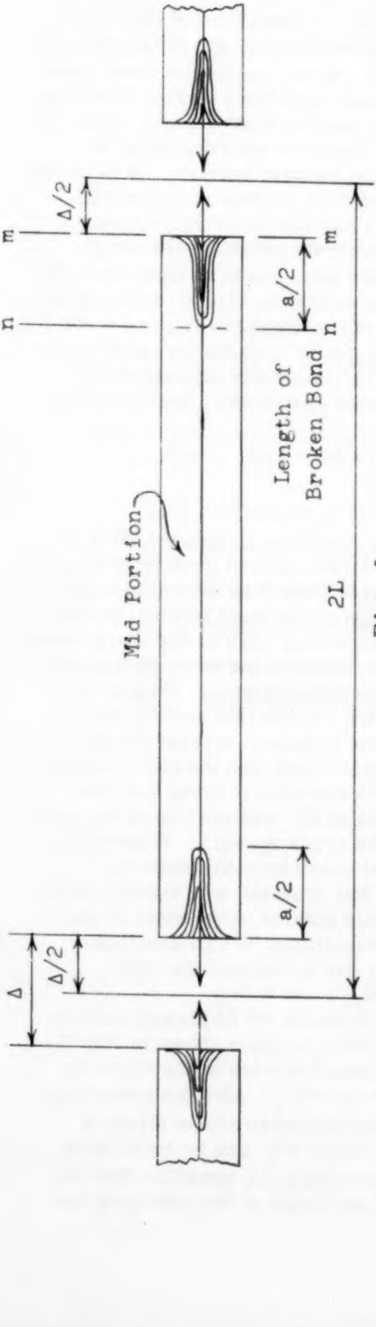
Δ/2
m
n
a/2
Mid Portion
Length of Broken Bond
2L
a/2
Δ/2
Δ

Fig. 1

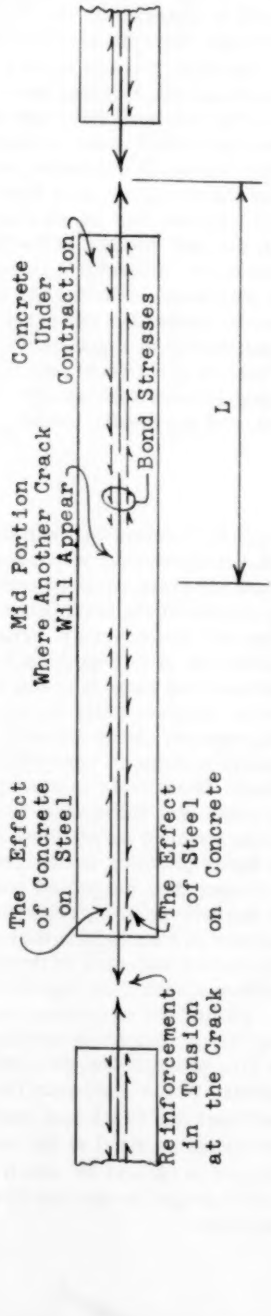
Concrete Under Contraction
Bond Stresses
L
Mid Portion Where Another Crack Will Appear
The Effect of Concrete on Steel
The Effect of Steel on Concrete
Reinforcement in Tension at the Crack

Fig. 2

From the geometry of the pavement section, a strain equation (1) is obtained, where a shrinkage shortening of "$\epsilon_{sh}L$" and a contraction of "$\alpha_c TL$" due to temperature drop attempt to take place. This otherwise free movement is resisted by the steel which is bonded to the concrete and causes an average concrete stress of "$f'_c/2$." When the tensile strength of the concrete is reached, a crack occurs at the mid-portion. At the cracks the steel alone restrains the cracked faces which results in such high bond stresses near the cracks that bond fails and concrete slips along the bar until a crack width "Δ" develops and a state of equilibrium results. The exact distribution of the bond stress is not known, nor need it be, for the present analysis. It is known that there will be zero bond stress at the crack face section m-m and full bond stress, that is, no slippage at section n-n and that bond will continue till the mid-portion of the pavement section under the most severe design condition. Therefore, in equation (1) the broken bond length is taken as "a/2" at both ends, reducing the bonded length of the section to "L-a." Equation (1) can be solved for the crack spacing "L" as given by Equation (2), and further modified as in Equation (3), if the unbonded length "a" is assumed to be zero. There is little doubt that the unbonded length "a" is greatly influenced by many factors such as rate of temperature change of concrete, degree of curing, and the traffic loads.

Area of Steel

If the friction between the subgrade and the pavement is ignored,[4] it is the reinforcement which forces the cracks to form. As can be seen in Fig. 2, when concrete tends to contract the steel tries to keep it to the same length by means of the bond between them. This action of the steel introduces tension into the concrete. The tensile force so formed is zero at the crack ends; maximum at mid-portion and always equal to the total bond force developed between the closest crack and the section under consideration. On the other hand, concrete pulls the steel at the crack which resists this pull by developing tension. Away from the crack, the presence of tensile stresses in the concrete helps to carry part or all of the tension which was developed in the steel. If concrete is strong enough it can force the steel to yield near the cracks. Yet if the steel is stronger the tension at the mid-portion of the concrete reaches its ultimate strength and another crack appears. Therefore to force cracking in concrete, the pulling steel cross sections must be stronger than the pulled concrete section, so that concrete will always crack at the mid-portion, relieving some of the tensile strains in the steel at the former cracks before they reach dangerous magnitudes.[5] To avoid uncontrolled widening of the cracks and distress due to fatigue, the steel stresses should be kept below the elastic limit.

To find the necessary percentage of steel, Equation (6) is formed satisfying the conditions of equilibrium for the free-body diagram shown in Fig. 3. In this equation the total force "F", which the steel carries at the crack is equated to the maximum tensile force of concrete "F'_1", plus the tension in the steel due to its own contraction "F_2" minus the compressive effect of shrinkage on steel at the mid-portion "F_3." Force "F_3" can be found from Equations (4) and (5) which are based on the compatibility condition that due to shrinkage the strains in steel and concrete are equal at the middle of the segment.

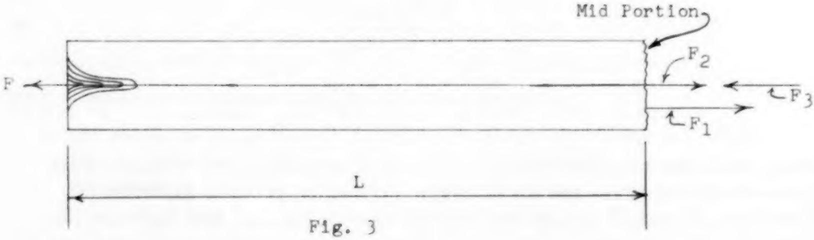

Fig. 3

F = Total tensile force which the steel carries at the crack

F_1 = Maximum tensile strength of concrete

F_2 = Tensile force developed in the steel due to its own contraction

F_3 = Compressive force developed in the steel due to shrinkage of concrete

p = percentage of steel

f_s = allowable tensile stress in steel

f'_s = compressive stress in steel

E_s = modulus of elasticity of steel

A_s = cross sectional area of steel

A_c = cross sectional area of concrete

$$n = \frac{E_s}{E_c} \qquad p = \frac{A_s}{A_c}$$

$$F_1 = A_c f'_c$$

$$F_2 = \alpha T p A_c E_s$$

$$\frac{f'_s}{E_s} = \epsilon_{sh} - \frac{f'_c}{E_c} \tag{4}$$

$$F_3 = f'_s A_s = (\epsilon_{sh} E_s - n f'_c)\, p\, A_c \tag{5}$$

$$F = F_1 + F_2 - F_3 = A_c \left[(f'_c + \alpha T p E_s) - (\epsilon_{sh} E_s - n f'_c)p\right] \tag{6}$$

$$F = p\, A_c f_s \tag{7}$$

$$p = \frac{f'_c}{f_s - nf'_c + E_s(\epsilon_{sh} - \alpha T)} \tag{8}$$

$$A_s = pA_c = \frac{f'_c A_c}{f_s - nf'_c + E_s(\epsilon_{sh} - \alpha T)} \tag{9}$$

Then, since the total force of steel "F" is also equal to the product of its cross-sectional area, and its allowable stress, as given in Equation (7), Equations (6) and (7) are solved simultaneously for "p," and Equation (8), giving the percentage of steel, is obtained. The necessary steel area can be found from Equation (9).

Necessary Bar Perimeter

The crack spacing "L" is primarily influenced by the amount of bond development along the length of the steel bars. When the total bond force developed between the crack and the mid-portion of the concrete section exceeds the ultimate tensile strength of concrete, another crack forms at the middle.

Bond development depends on the perimeter of the bars when the type of steel and concrete are already determined.

If μ = average bond stress through length "L"

Σ_o = total perimeter of bars

then

$$\mu \Sigma_o L = A_c f'_c \tag{10}$$

$$\Sigma_o = \frac{A_c f'_c}{\mu L} \tag{11}$$

By equating the maximum pull "$A_c f'_c$" that the steel can exert on concrete to the available bond strength "$\mu \Sigma_o L$" along length "L" of the bar, Equation (10) is obtained. When this is solved for "Σ_o," Equation (11) gives the amount of bar perimeter needed to develop the bond strength necessary to insure a maximum crack spacing "L" under the most severe design condition. Since the average bond strength along a specific length is used in Equation (11), uncertain aspects like the bond stress distribution and bond slip are of no importance. "μ" can be obtained from pullout bond tests when more elaborate data on it is not available.

The assumption of full restraint at the ends of the slab on which this analysis is based, represents the severest design condition for the reinforcement. Therefore the use of the same steel found by means of the derived equations, through the whole length of the pavement, is feasible. In doing this, uneconomical use of steel will be minor, because of the relative shortness of the moving ends.

CONCLUSION

To design the steel in continuously reinforced concrete pavements:

1. Decide on a maximum permissible crack width.
2. By means of Equation (2), find the necessary crack spacing which insures that the maximum permissible crack width will not be exceeded.
3. By means of Equations (8) and (9), find the needed percentage of steel and steel area.
4. By means of Equation (11), find the needed bar perimeter.
5. Choose reinforcement satisfying the needs of the steel area and perimeter.

Numerical Example

Given:	$\Delta = 0.02$ in.
	$T = 80^{o}$ Fahrenheit
Pavement thickness	= 8 inches
Pavement width	= 10 feet = 120 inches
	$\epsilon_{sh} = 0.0002$ inches per inch
	$f'_c = 400$ pounds per square inch
	$E_c = 3{,}000{,}000$ pounds per square inch
	$\alpha = 0.000006$ per degree Fahrenheit
	$f_s = 70{,}000$ pounds per square inch
	$E_s = 30{,}000{,}000$ pounds per square inch
	$a = 10$ inches
(for deformed bars)	$\mu = 300$ pounds per square inch

From Equation (2)

$$L = \frac{0.02 - \frac{1/2(400)10}{3\ 000\ 000}}{0.0002 + 0.000006(80) - \frac{1/2(400)}{3\ 000\ 000}} = 35 \text{ inches}$$

From Equation (8)

$$p = \frac{400}{70\ 000 - 10(400) + 30\ 000\ 000\ [0.0002 - 0.000006(80)]} = 0.007$$

$$A = 0.007\ (8)(120) = 6.72 \text{ square inches}$$

From Equation (11)

$$\Sigma_o = \frac{8(120)(400)}{(300)35} = 36.5 \text{ in.}$$

Use 22 - 5/8 in. ϕ whose A_s = 6.82 square inch

$$\Sigma_o = 43.1 \text{ inch}$$

ACKNOWLEDGMENT

Although this paper was written in a short period on the author's free time, it would not have been possible for him to reach the understanding of the pavement behavior which is being reflected, if he had not worked on the Continuously Reinforced Concrete Pavement Research Project undertaken by Lehigh University under the sponsorship of the Bureau of Public Roads and Pennsylvania Department of Highways. The author is indebted to those sponsors and especially to Professors W. J. Eney and G. Dinsmore and to Messrs. I. J. Taylor, and F. Cain of Fritz Engineering Laboratory for their valuable assistance.

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Paper 1800 October, 1958 HW 3

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TESTS OF CONCRETE PAVEMENTS ON GRAVEL SUBBASES

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(Proc. Paper 1800)

SYNOPSIS

Concrete pavement slabs 8 in. by 12 ft by 18 ft joined by 1-in. round dowels were subjected to static loads to study the effect of various thicknesses of open-graded sand and gravel subbases upon the strength of the composite pavement structure. Deflections and strains in the concrete and pressures on the subbase and subgrade were measured for eight load positions when the slab was flat and when it was curled upward at corners and edges.

This is the second phase of a comprehensive study which is concerned primarily with subbases and secondarily with slab deflections and stresses and with interface pressures. Where load conditions permitted comparisons, it was found that trends reported in the first phase in testing 6-in. slabs on dense-graded sand and gravel subbases(1) were supported by the present study, although magnitudes were affected by subbase material and slab dimensions.

The present experiments showed that open-graded sand and gravel subbases under flat slabs were more effective in reducing free-corner and free-edge deflections than in reducing strains. Computations based upon the test data and a theoretical treatment showed that under free-corner loads the deflection of an 8-in. slab on a 7.5 in. subbase would be about equal to that for a 9-in. slab with no subbase. However, a subbase 17 in. thick would hold corner strains in an 8-in. slab equal to those in a 9-in. slab with no subbase. Under edge loads the subbases were less effective in reducing deflections and strains than under corner loads.

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Deflections and strains for loads at doweled corners of flat slabs were reduced to 60% and 70%, respectively, of corresponding values at free corners. A load 1 ft inward transversely from the free corner position further reduced deflections to 40% of the free corner value. A load 1 ft inward from the free edge reduced both deflections and strains to 70% of the free edge value.

Pressures between the slab and subbase increased with subbase thickness but pressures on the subgrade diminished slightly as subbase thickness increased. Subgrade pressures under typical pavement loads were of the order of 5 to 6 psi for extreme edge loads and 2 to 3 psi for interior loads.

Experimental deflections and strains for interior, edge, and corner loads were compared with theoretical curves based upon the liquid subgrade hypothesis. Both deflections and strains obtained under interior loads on curled and flat slabs were slightly greater than those computed by Westergaard's 1926 or 1947 equations. Test deflections and strains at edges due to edge loads were close to those computed from Westergaard's 1947 equations for both flat and curled slabs. Under free corner loading the test deflections for flat slabs were in good agreement with Westergaard's 1926 equation but were greater than indicated by theory for curled slabs. Test strains near corners were between those computed by the 1926 equation and Pickett's equation when the slabs were flat but were in better agreement with the latter when the slabs were curled.

INTRODUCTION

Frequent heavy loads on concrete highways have revealed construction requirements which were not readily apparent under the lighter traffic prior to 1940. In some areas where traffic exceeded that for which the road was designed, pavements have developed faulted joints and structural cracks, frequently preceded by edge or joint pumping which contributed to a loss of subgrade support.

The need for a uniform foundation of reasonably constant bearing value became evident, and subbases were specified in new construction on fine-grained soils. These were generally of granular material and were either dense-graded to prevent concentrations of free water from reaching the subgrade, or open-graded to allow drainage to the side ditches.

Benefit from subbases was obtained in most cases. Roads built in areas where the native subgrade was clay or silt were greatly improved. The use of granular subbases, however, introduced problems of gradation, thickness, and method of placement of subbase materials to prevent faulting and pumping. The extent of the structural contribution made by subbases of different thickness to the pavement structure was also an important factor. Hence a comprehensive study on subbases was begun at the Portland Cement Association Laboratories.

Scope of the Program

This investigation is designed to study the effects of several types and thicknesses of subbase material on the load-carrying characteristics of concrete slabs. Tests are made on full-scale slabs on subbase materials and thicknesses which include those in actual use under concrete pavements. The

first phase of this study on dense-graded sand and gravel subbases has been completed and reported.[1] A second phase on open-graded sand and gravel subbases is reported in this paper, and tests are now in progress on open- and dense-graded crushed stone. These will be followed by an investigation of cement-treated materials. The studies will provide information on the effect of gradation, permeability, particle shape, and cement treatment.

The tests reported here are on 8-in. thick concrete slabs built on subbases 5, 10 and 15 in. thick constructed on a silty clay subgrade soil. Evaluation procedure involves observations of slab strains and deflections and subbase and subgrade pressures when static loads are applied to the paving slab. Control is maintained over slab thickness, subbase thickness, subgrade thickness, temperatures, subbase and subgrade moistures and densities, and slab shape (flat or curled upward at corners and edges).

Specific Objectives

The objectives of the program are:

1. To determine the effect of thickness of subbase on the load carrying characteristics of the slab.

2. To investigate the effect of subbases in distributing pressures to the subgrade.

3. To obtain information helpful in establishing relationships between slab thickness and subbase thickness to effect economy in design.

4. To compare experimental load-strain-deflection relationships with those computed in accordance with the theory that deflection is everywhere proportional to pressure, as in the Westergaard theory.

Facilities and Materials

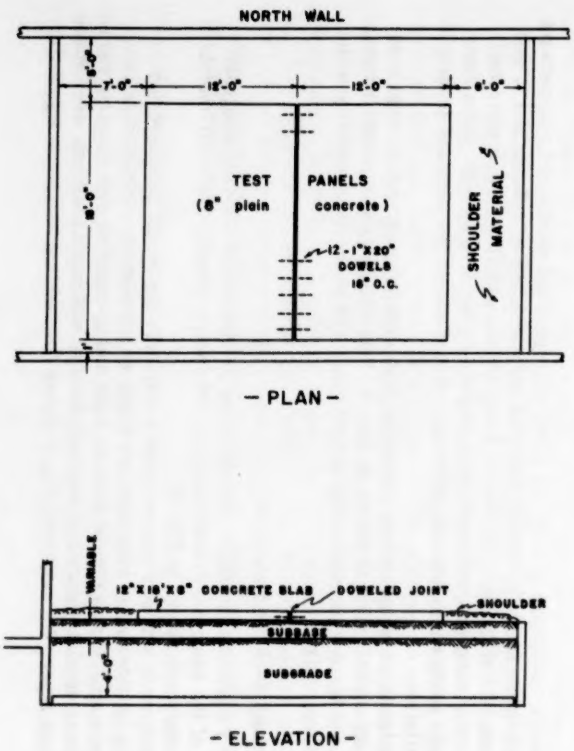
Tests are conducted in a 24- by 37-ft waterproofed reinforced concrete pit described in the first report.[1] The test pit was filled to a depth of 4 ft with well compacted silty clay. Subbases 5 in., 10 in., and 15 in. thick were built upon the clay subgrade and pairs of doweled 12- by 18-ft by 8-in. plain concrete slabs were cast upon the subbases. Fig. 1 shows the plan and profile of the installation.

Static loads were applied by hydraulic jacks reacting against an overhead frame. An overall view is shown in Fig. 2. The reinforced concrete building in which the tests were made was heated to permit year-round activity with temperature control.

Subgrade and Subbase Materials

Table 1 presents gradation and physical properties of the clay subgrade soil and of the sand and gravel subbase. Moisture-density and CBR-moisture relationships are shown in Fig. 3.

The subgrade soil was spread upon a concrete apron and prepared for placement by working it with a rotary tiller at a moisture content slightly above optimum. It was placed in 6-in. lifts and compacted with tamping rammers. Bearing plate tests and in-place density and moisture tests were made on one-foot layers for control. Fig. 4 shows the bearing values on top of the



LAYOUT OF TEST PANELS

Fig. 1

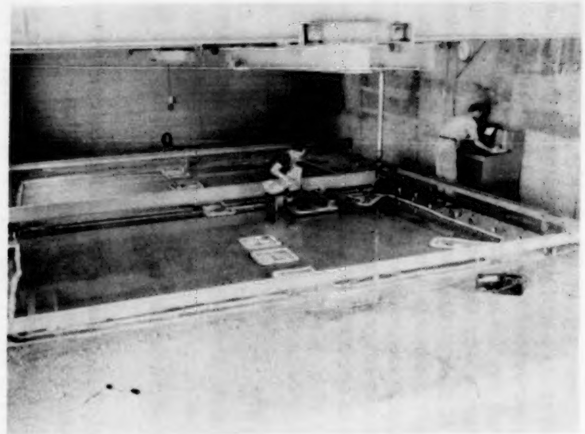


Fig. 2 Overall View of Test Area. Slabs flooded to prevent upward curl due to surface drying.

TABLE 1

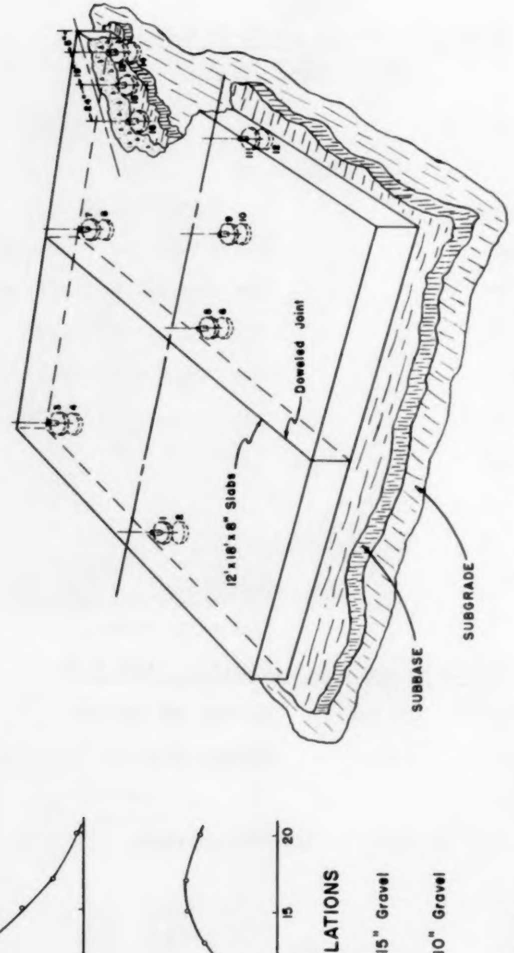
GRADATION AND SOIL LIMITS OF SUBGRADE AND SUBBASE MATERIALS

GRANULAR SUBBASE		CLAY SUBGRADE	
Gradation			
Sieve	% Passing	Particle Size	%
1"	100	Coarse Sand (2.0 - 0.42 mm)	6
3/4"	98	Fine Sand (0.42 - 0.074 mm)	8
3/8"	85	Silt (0.074 - 0.005 mm)	48
#4	68	Clay (below 0.005 mm)	38
#10	43	Colloids (below 0.001 mm)	30
#40	12		
#200	2		
Soil Constants			
Non Plastic		Liquid Limit	36
		Plasticity Index	19
Moisture-Density Relationships, AASHO T 99			
Maximum Dry Density*	135 PCF	Maximum Dry Density	112 PCF
Optimum Moisture*	7.3%	Optimum Moisture	16.2%

*Includes No. 4 to 1" aggregate in the test specimen

subgrade at 0.05 in. deflection for plates having diameters of 12, 16.6, 24, and 30 in. Westergaard's subgrade modulus k, determined with a 30-in. plate, was 75 pci.

The subbase material was a bank-run sand and gravel which had been run through a crusher to hold the maximum size to 1 in. The material was placed in lifts and vibrated to the required density. The full 15-in. thickness was placed and tested first, and the thickness was reduced to 10 in. and to 5 in. by cutting off the top layers for the second and third tests. After cutting, some reworking of the subbase surfaces was necessary for fine grading to obtain uniform slab thickness. Plate bearing values on all three subbase thicknesses are shown in Fig. 4. Westergaard's modulus k for each subbase thickness is given in Table 3.



Cells 1,3,5,...etc. between slab and subbase
Cells 2,4,6,...etc. between subbase and subgrade

PRESSURE CELL LOCATIONS

Fig. 5

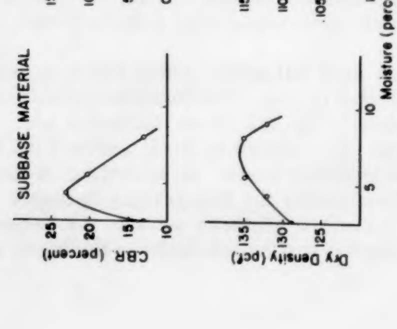


Fig. 3 - M-D AND CBR RELATIONS

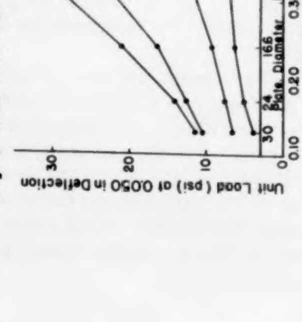


Fig. 4 - FOUNDATION BEARING VALUES

Concrete Pavement Panels

The pavement for each test included two 12-ft by 18-ft by 8-in. panels separated by a 3/16 in. joint with sheet metal full-depth parting plate and doweled along the 18-ft edge by 1- by 18-in. slip dowels on 18-in. centers. The dowels established deflection continuity across the joint. The joint construction also permitted a comparison of strains, deflections, and pressures at the outer boundaries of the slab with those in the area of dowel restraint.

The concrete, mixed in the laboratory, had a cement factor of 6 sk per cu yd, a water-cement ratio by weight of 0.50, a slump of 3 in. and an air content of approximately 5%. The properties of fog-cured test specimens are given in Table 2.

TABLE 2

CONCRETE PROPERTIES

Slab Foundation	Age Days	Strength - psi: Cylinder Compression	Strength - psi: Beam Flexure	Dynamic E Million psi: Cylinder	Dynamic E Million psi: Beam
	7	3400	530	4.5	4.5
Clay	14	4000	590	4.7	4.8
	28	4600	650	4.9	5.2
	7	4400	500	4.3	4.8
5"	14	5200	580	4.7	5.2
Subbase	28	5500	640	5.2	5.4
10"	14	4800	660	5.4	5.3
Subbase	28	5700	700	5.6	5.6
15"	28	4500	620	4.7	4.8

The test slabs were cured 7 days under wet curlap, then ponded until the loading tests for the flat slabs were completed. At the end of this period, usually 5 to 6 weeks, the water was removed, the slabs were permitted to dry from the top and the load tests were repeated on the curled slabs.

Instrumentation

Instruments for the measurement of strain, deflection, and pressure were the same as described in the previous report,(1) namely, SR-4 type A-9 bonded strain gages on the slab surface, 0.001-in. dial indicators attached to

a wooden bridge for deflection measurement, and Carlson stress meters for pressure indication. Pressure cell and strain gage locations are shown in Figs. 5 and 8 respectively.

In addition to deflections due to loads, the vertical deformations of the slabs due to drying shrinkage were measured. For this purpose a loose-pin deflectometer was used. This permitted readings of slab position at any time without the necessity of a permanent dial installation at each measuring point. The deflectometer is illustrated in Fig. 6. The brass housing was attached to a reference rod driven into the subgrade, and the loose pin rested upon a target on the slab surface. The dial indicator equipped with an adapter measured the change in the distance from the top of the pin to the machined face of the brass housing.

Test Details

Bearing plate tests were made upon the subgrade before and after completion of the tests on subbases, and at four locations on each subbase. The average k value and associated in-place moisture and in-place density for each subbase thickness are given in Table 3.

TABLE 3

IN-PLACE TESTS ON SUBGRADE AND SUBBASES

Subbase Thickness in.	In-Place Dry Density pcf	Moisture Content %	k from 30" Plate 0.05" Deflection pci
0*	111	20.0	75
5	132	4.6	130
10	137	4.7	200
15	135	4.9	225

* Tests on Subgrade

Static loads on the slabs were applied by hydraulic jack to a 12-in. diameter steel plate resting upon a firm rubber pad the same size as the plate. Load intensity was measured with Baldwin load cells and an SR-4 indicator. A typical test is illustrated in Fig. 7. Load tests were made at the following locations: free corner, doweled corner, free edge, doweled edge, interior, inward from the free corner, inward from the doweled corner, and inward from the free edge. The 8 load positions are shown in Fig. 8. The loads were applied in increments of 3,000 lb, and in most cases the maximum load was 15,000 lb. At position 1, maximum deflections were at the load and maximum tensile strains were assumed to be equal to the maximum measured compressive strains under the load. At positions 2, 5, and 6, maximum deflections were measured at the slab edge and maximum tensile strains were assumed to be equal to the maximum compression indicated by the gage at the slab edge. At positions 3 and 4 maximum deflections occurred at the

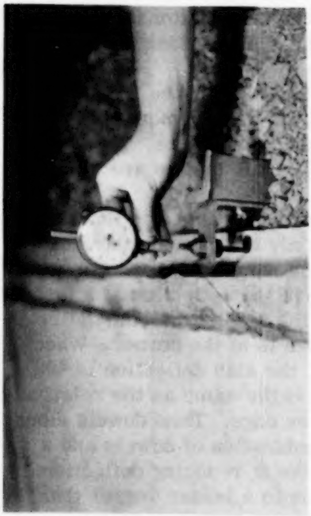


Fig. 6 Deflectometer for Measurement of Elevation Changes due to Curl.

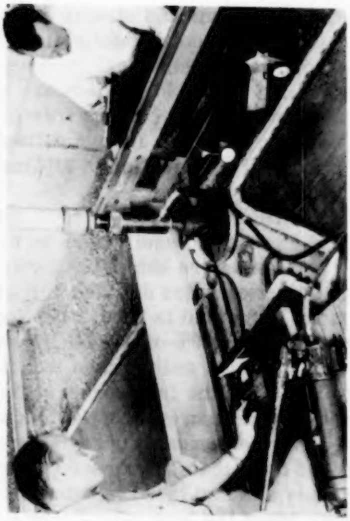
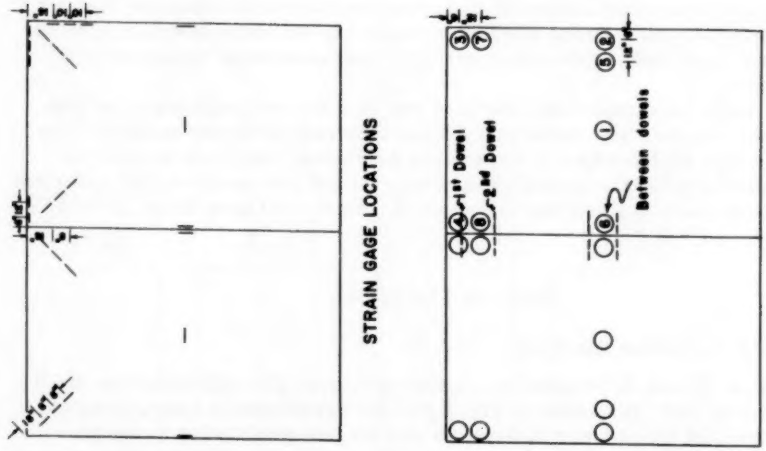


Fig. 7 Typical Load Test.



LOAD POSITIONS

Fig. 8

corners. Maximum tensile strains were measured on the corner bisector at some distance inward from position 3, but were found to be along the doweled edge for position 4. For positions 7 and 8 maximum deflections occurred at the corners and the magnitude of compressive strains on the slab edges at the point of plate tangency exceeded that of any tensile strain along the slab edge or corner bisector. Hence maximum tensile strains were assumed to be of the same magnitude as the maximum compression strains measured at the slab edges.

The tests were made when the slab was in a flat state and when the slab edges and corners had curled upward due to drying at the top surface. The study of slab deflections and strains and foundation pressures was not as comprehensive for the curled condition as for the flat condition, but sufficient tests were made to illustrate the effect of upward curl upon these measurements.

Tests on Flat Slabs

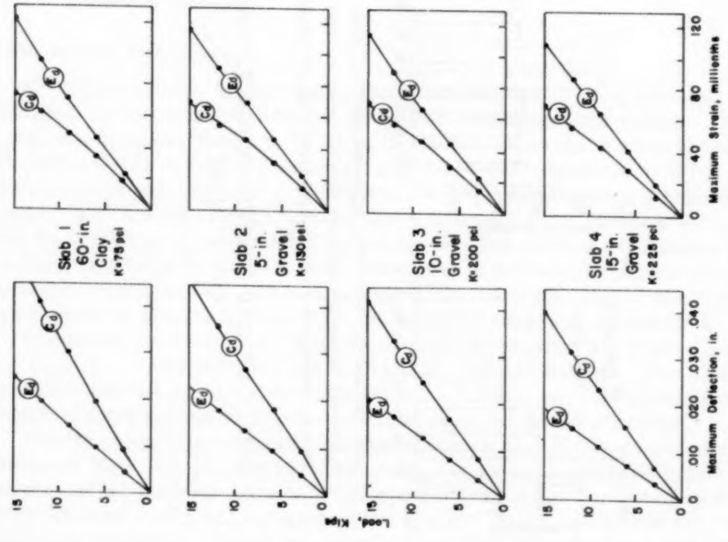
Maximum Deflection and Strain

Figs. 9, 10 and 11 present the measured strains and deflections for the 8 positions of load. It is seen in Fig. 9 that the relationships among interior, free edge, and free corner deflections and strains established in the previously reported tests(1) on 6-in. slabs with dense-graded subbases are maintained. Free corner deflections greatly exceed free edge deflections, but the maximum strain under edge loads exceeds the maximum strain produced by loads at the corners. At doweled edges and corners, as seen in Fig. 10, the deflections and strains are reduced but the relationship is the same as before, i.e., corner deflections exceed edge deflections and edge strains exceed corner strains.

As shown in Fig. 11, when loads are applied inward from the free edge, free corner, and doweled corner, free corners again deflect more than doweled corners and these in turn deflect more than free edges. However, there is a marked equalization in strains, and all strain curves are closely grouped.

The influence of load position upon deflections and strains in a flat slab for a 10,000-lb load is readily seen in Fig. 12. Only the data for the slabs on the 5-in. subbase are shown but the trend is the same for all subbases. The deflection at a loaded doweled corner is 57% of the deflection at a loaded free corner. If the load is inward one foot from the free corner the deflection of the corner is 70% of the value when the load is at the corner. When the corner is doweled and the load is 1 ft inward, the slab deflection is 40% of that for a load on the free corner. This value is the same as the relatively small deflection measured with the load at the free edge. Thus dowels alone restrain corner deflections appreciably and a combination of dowels and a load path 1 ft from the slab corner is very effective in reducing deflection.

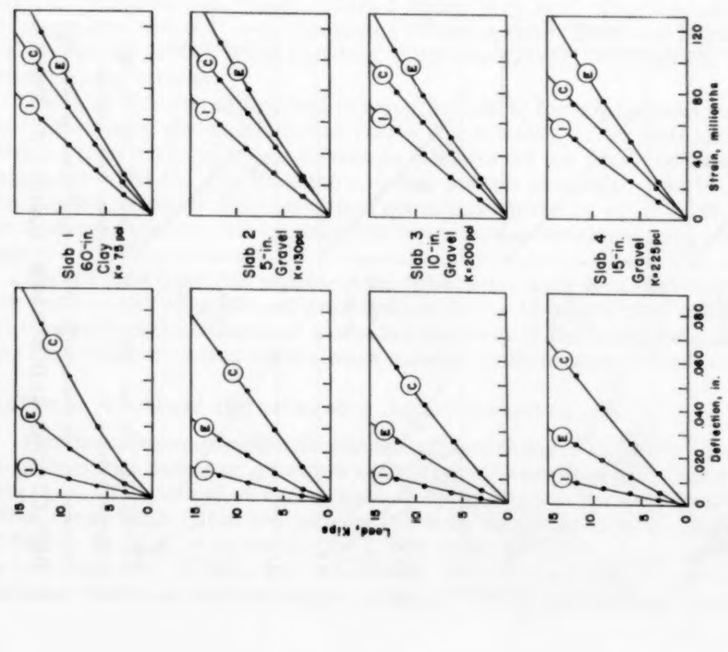
Strains are affected by dowels and load position to a lesser degree than deflections. When the load is at a free edge the strain is 21% greater than that due to a load at a free corner. Strain due to a load at a doweled edge is 16% less than that at a free edge, but still exceeds strain for a free corner load. When the load is 1 ft inward from the free edge, the maximum strain is 58% of the strain due to a free edge load. This maximum strain remains about the same when the load is 1 ft in from the edge at either a doweled or



Load at Doweled Edge E_d and Doweled Corner C_d

DEFLECTIONS AND STRAINS

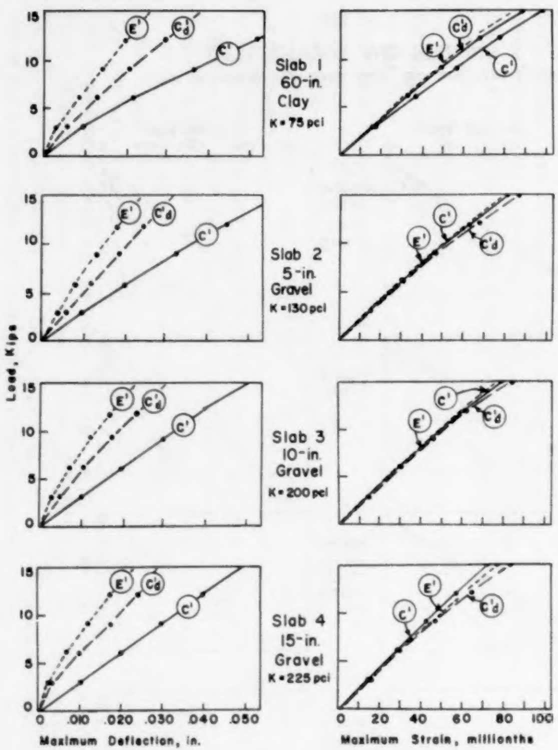
Fig. 10



Load at Interior (I) Free Edge (E) and Free Corner (C)

DEFLECTIONS AND STRAINS

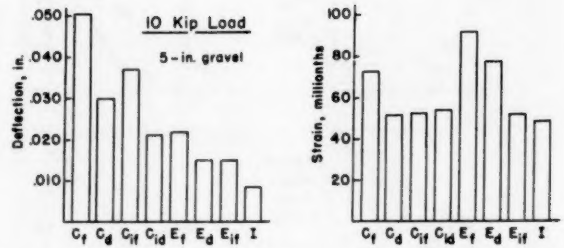
Fig. 9



Load inward 1 ft. from Free edge (E'), Free corner (C') & Doweled corner (C'd)

DEFLECTIONS AND STRAINS - LOADS 1 FT. INWARD

FIG. 11



Load Positions - C_f = Free Corner, C_{if} = Inward from Free Corner
C_d = Doweled Corners, C_{id} = Inward from Doweled Corner, E_f = Free Edge, E_{if} = Inward from Free Edge, E_d = Doweled Edge, I = Interior

EFFECT OF LOAD POSITION ON DEFLECTIONS AND STRAINS

Fig. 12

free corner. The maximum strains developed by loads 1 ft inward from the free edge or corner of the slab are only slightly greater than those for an interior load. The effect of load position is significant and warrants consideration in pavement design.

Comparison with Theory

Several equations are available for computing theoretical stresses and deflections for comparison with the measured (experimental) values. The equations used are listed in Table 4. Numbers 1 through 6 were developed by Westergaard(2) in 1926. Numbers 7 and 8 are 1933 modifications by Westergaard. Kelley's(3) modification for edge stresses is equation 9 and Pickett's(4) formula for corner stresses is equation 10. Numbers 11, 12, 13 and 14 are Westergaard's 1947 equations.(5) The stresses computed by the various equations in Table 4 were converted to strains for direct comparison with experimental data. In making this conversion the biaxial effect resulting from loads at positions other than the extreme edge was considered.

Constants for stress and deflection computation are: $h = 8$ in., $r = 6$ in., $u = 0.15$, $E = 4,500,000$ psi, and $k = 75$, 130, 200 and 225 pci. The elastic modulus was not exactly 4,500,000 psi for all tests, but variations in E were minor and did not cause significant changes in computed stresses.

Charts comparing experimental and theoretical deflections and strains are shown in Figs. 13, 14, and 15. Generally, the experimental deflections and strains at the interior were slightly greater than those computed by theory. Westergaard's original equations gave a much better check than his 1933 modified equations. Lines representing the 1947 equations (11 and 12) would have been almost coincident with 1 and 2.

At the free edge, aside from low experimental deflections for the slab on clay, the experimental values matched theory very well. Experimental deflections agree closely with Equation 4 (Westergaard: 1926) and Equation 14 (Westergaard: 1947), while Equation 13 (Westergaard: 1947) agrees with experimental strains.

There is only one theoretical curve (Equation 6) for comparison with corner deflections, and experimental values check theory rather well except for slab 1. Experimental values of strains fall between the limits defined by equations 5 and 10, with Equation 5 having a slight advantage over 10. It is reasonable to expect that theoretical strains computed by equation 10 would exceed experimental values since this equation was developed for curled slabs.

For all load positions experimental deflections were less than theoretical for tests on the subgrade and greater than theory for the thicker subbases. This sensitivity to changes in k was not apparent in the strain data where the experimental values were always bounded by theoretical curves.

Influence of Subbase Thickness upon Deflections and Strains

Maximum experimental deflections and strains for a 10,000-lb load on 8-in. concrete panels on subbases of different thicknesses are plotted in Fig. 16A. The deflection curves have steepest slope in the segments 0 to 5 in. Free corner deflections are reduced 0.009 in. by a 5-in. subbase compared to 0.014 in. by 15 in. of subbase. Thus, 64% of the reduction is accomplished by a 5-in. subbase. At the edge, deflections were reduced 0.003 in. by the 5-in. subbase thickness, with no further reduction due to additional thickness of

TABLE 4

DESIGN EQUATIONS

(Circular Loading Area, Radius r)

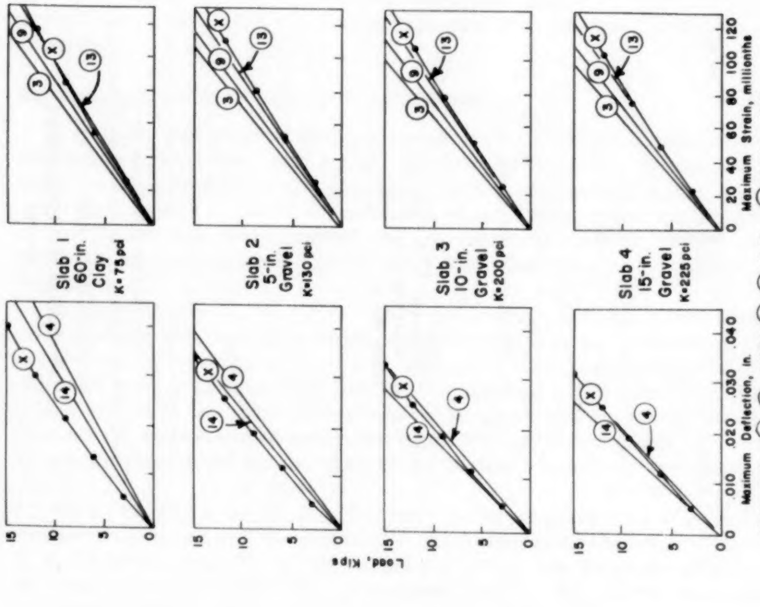
Load Position	Source and Date	Equation No.	Simplified Equation
			Maximum Stress, psi
Interior	W - '26	1	$S_i = S_1 = 0.275\,(1+u)\frac{P}{h^2}\left(4\log\frac{L}{B} + 1.069\right)$
Edge	W - '26	3	$S_e = 0.529\,(1+0.54u)\frac{P}{h^2}\left(4\log\frac{L}{B} + 0.359\right)$
Corner	W - '26	5	$S_c = \frac{3P}{h^2}\left[1 - \left(\frac{r\sqrt{2}}{L}\right)^{0.6}\right]$
Interior	W - '33	7	$S_i = S_1 - 15\,(1+u)\frac{P}{h^2}\left(\frac{L}{L_1}\right)^2 Z$
Edge	K - '39	9	$S_e = 0.529\,(1+0.54u)\frac{P}{h^2}\left(4\log\frac{L}{B} + \log B\right)$
Corner	P - '46	10	$S_c = 4.20\frac{P}{h^2}\left(1 - \frac{\sqrt{r}L}{0.925L - 0.22r}\right)$
Interior	W - '47	11	$S_i = 0.275\,(1+u)\frac{P}{h^2}\left(4\log\frac{L}{r} + 1.069\right)$
Edge	W - '47	13	$S_e = \frac{1+u}{3+u}\frac{P}{h^2}\left[8.80\log\frac{L}{r} - \frac{4u}{\pi} - 0.290 + \frac{3}{\pi}\left(\frac{1-u}{2} + 1.18\,(1+2u)\frac{r}{L}\right)\right]$
			Maximum Deflection, in.
Interior	W. - '26	2	$d_i = \frac{P}{8kL^2}$
Edge	W - '26	4	$d_e = 0.409\,(1+0.40u)\frac{P}{kL^2}$
Corner	W - '26	6	$d_c = \left(1.10 + 1.24\frac{r}{L}\right)\frac{P}{kL^2}$
Interior	W - '33	8	$d_i = (1 - Z)\frac{P}{8kL^2}$
Interior	W - '47	12	$d_i = \frac{P}{8kL^2}\left[1 - 0.183\frac{r^2}{L^2}\left(2\log\frac{L}{r} - 0.117\right)\right]$
Edge	W - '47	14	$d_e = P\sqrt{\frac{2 + 1.20u}{Eh^3k}}\left[1 - (0.76 + 0.40u)\frac{r}{L}\right]$

W = H. M. Westergaard, K = E. F. Kelley, P = Gerald Pickett

P = Total load, lb., h = slab thickness, in., u = Poisson's ratio, E = Elastic modulus of concrete, psi, Z = deflection ratio, L_1 = Multiple of L, k = Subgrade modulus, pci, $L^4 = \frac{Eh^3}{12\,(1-u^2)k}$, $B = \sqrt{1.6r^2 + h^2} - 0.675h$

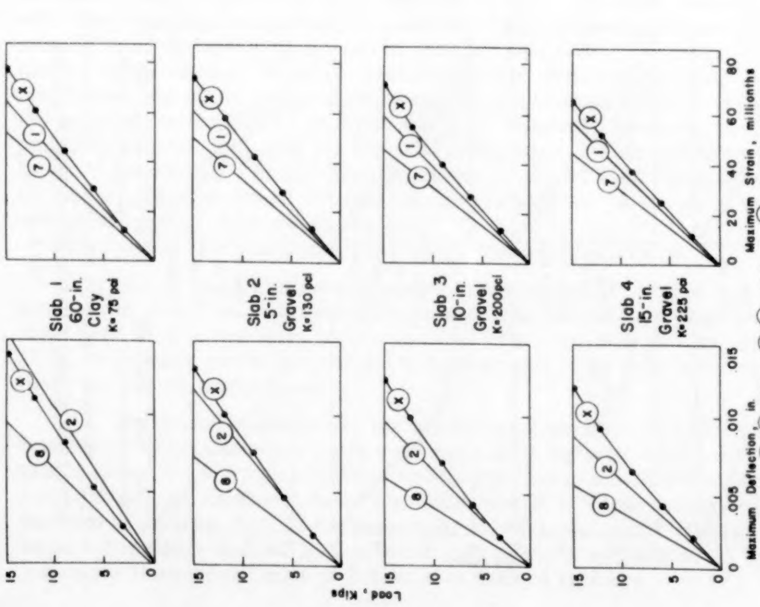
subbase. At the interior, a total reduction of 0.002 in. was accomplished by 15 in. of gravel; the 5-in. layer accounted for 0.001 in.

The study of effect of subbase thickness on strain showed that the reduction in slab strain per inch of subbase thickness is not significantly different for the 5-in. layer than it is for the thicker subbases. The greatest effect was found for free corner loading, where strains were reduced 15% by increasing the subbase thickness from 5 in. to 15 in.



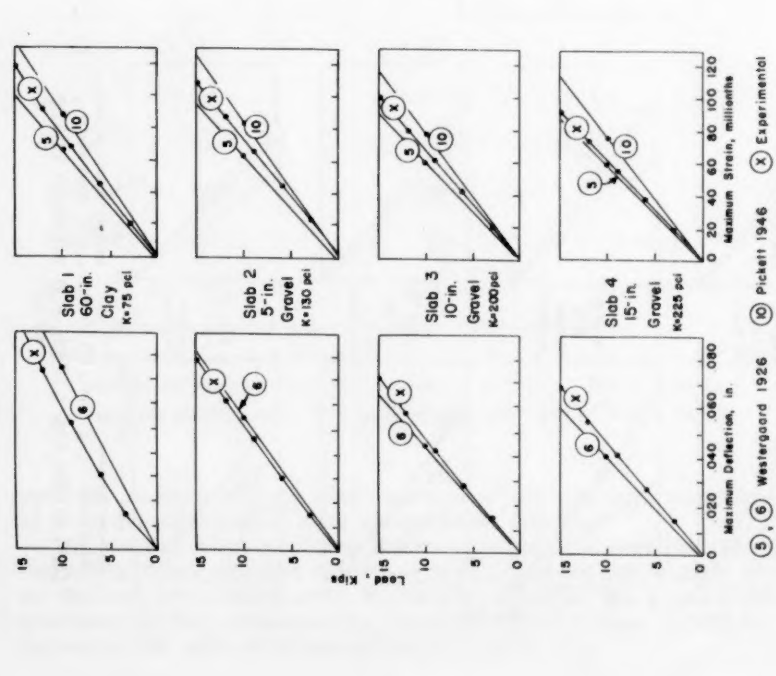
DEFLECTION AND STRAIN FOR EDGE LOADS

FIG. 14



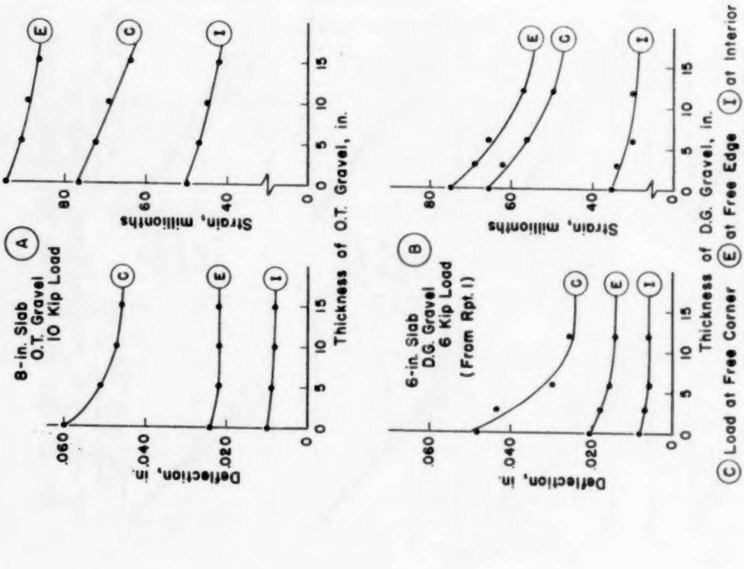
DEFLECTION AND STRAIN FOR INTERIOR LOADS

FIG. 13



DEFLECTION AND STRAIN FOR CORNER LOADS

FIG. 15



DEFLECTION AND STRAIN VS SUBBASE THICKNESS

Fig. 16

Curves from tests[1] on 6-in. slabs on dense-graded subbases have been reproduced in Fig. 16B for thicknesses up to 15 in. Comparing the two sets of curves, A and B, it is seen that the 6-in. slabs on dense-graded sand and gravel are more sensitive to subbase structure than 8-in. slabs on open-graded sand and gravel, but the general effects of subbase thickness are similar.

Subbase Evaluation in Terms of Slab Thickness

It is important to know whether a road structure can be made adequate in resistance to deflection and strain, and more economical, by building thin slabs on thick subbases, or by building thick slabs on subbases of the minimum thicknesses required to prevent pumping. Although at this writing there is insufficient test data for complete experimental analysis, theory and experiment can be combined to evaluate various combinations of slab-subbase thickness.

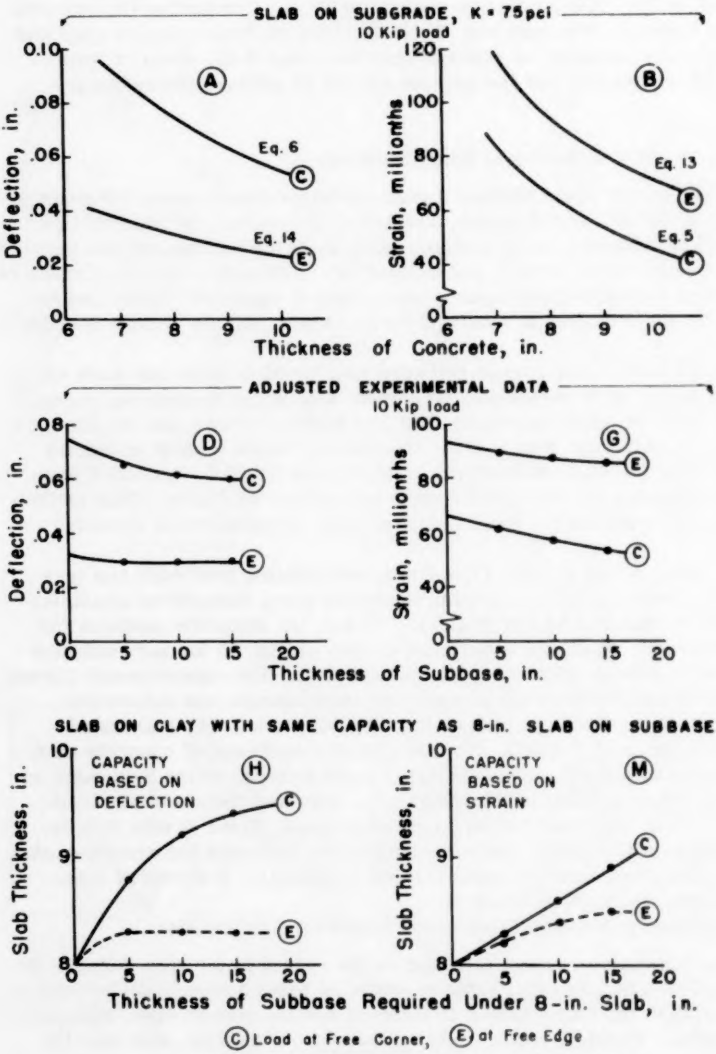
In Figs. 14 and 15, for corner and edge loading, it is seen that each experimental curve is in reasonable agreement with some theoretical curve. Therefore, by a combination of test data and theory, curves may be constructed from which one may find the thickness of slabs without subbases which will show the same deflections or strains as thinner slabs built upon various thicknesses of open-graded sand-and-gravel subbases. This method of analysis was used for the 6-in. slabs on dense-graded gravel reported earlier.

First, curves A and B, Fig. 17, were drawn relating free edge and free corner deflections and strains to slab thickness using theoretical equations 5, 6, 13 and 14 with $P = 10{,}000$ lb and $k = 75$ pci, the subgrade modulus for the clay subgrade. Next, the experimental data of Fig. 16 for zero subbase thickness were compared with the theoretical data. The experimental curves were then translated vertically to make the experimental and theoretical results coincide for the 8-in. slab on the clay subgrade. The translated curves are designated D and G. Now, to find the thickness of concrete on a clay foundation which will give deflections equal to those of the 8-in. slab on the subbase, select a subbase thickness in D, intersect the curve for load positions desired, and read the adjusted deflections. Enter A with this deflection, intersect the proper load-position curve, and read the resulting slab thickness. The procedure for equal strains is similar. A series of these operations produced curves H and M.

This method of evaluation leads to the following conclusions:

1. The subbase was most effective in the region of the free corner. In this region, 7-1/2 in. of gravel subbase would be needed to hold <u>deflections</u> of an 8-in. slab to the same values as those of a 9-in. slab on clay, whereas 17 in. of subbase would be required to hold <u>strains</u> of an 8-in. slab equal to those for a 9-in. slab on clay.

2. The gravel subbase was not particularly effective in reducing slab deflections or strains when loads were applied at the edge. Five inches of gravel under the 8-in. slab made it as effective as an 8.3-in. thick slab without subbase. No additional benefit was derived from thicker subbases. In the case of strains, 7 in. of subbase under an 8-in. slab made it as effective as an 8.3 in. thick slab without subbase, and 15 in. of subbase under an 8-in. slab made it as effective as an 8.5 in. slab without subbase.



SUBBASE STRENGTH IN TERMS
OF SLAB THICKNESS

Fig. 17

The minor contribution to strength of the road structure by open-graded gravel subbases thicker than 5 in. is corroborated later in the report (Fig. 24). It seems doubtful that it would be economical to use these subbases in thicknesses greater than that necessary for pumping and frost control.

Maximum Subbase and Subgrade Pressures

Pressures between the slab and subbase and between subbase and subgrade were measured with Carlson stress meters. Relations between pressure and applied load for various load positions are shown in Fig. 18.

In general, pressures between the slab and subbase increased with greater subbase thicknesses. Fig. 19A shows this trend for 12,000-lb loads. This effect was negligible at the interior of the slab but when the load was at the corner the pressures on the subbase increased approximately 1 psi for each inch of subbase thickness. However, as seen in Fig. 19B the pressures on the subgrade did not increase and in fact decreased as the subbase was increased from 5 to 15 in.

Since a 12-kip wheel load was used to plot the data of Fig. 19B, the pressures are likely to be slightly greater than those under 8-in. pavements under legal loads approximating 9 kips per wheel. Thus sub-grade pressures in the field under conditions similar to those of this test would be 5 to 6 psi at slab edges and doweled corners, and 2 to 3 psi at interior positions.

Pressure-Deflection Relations

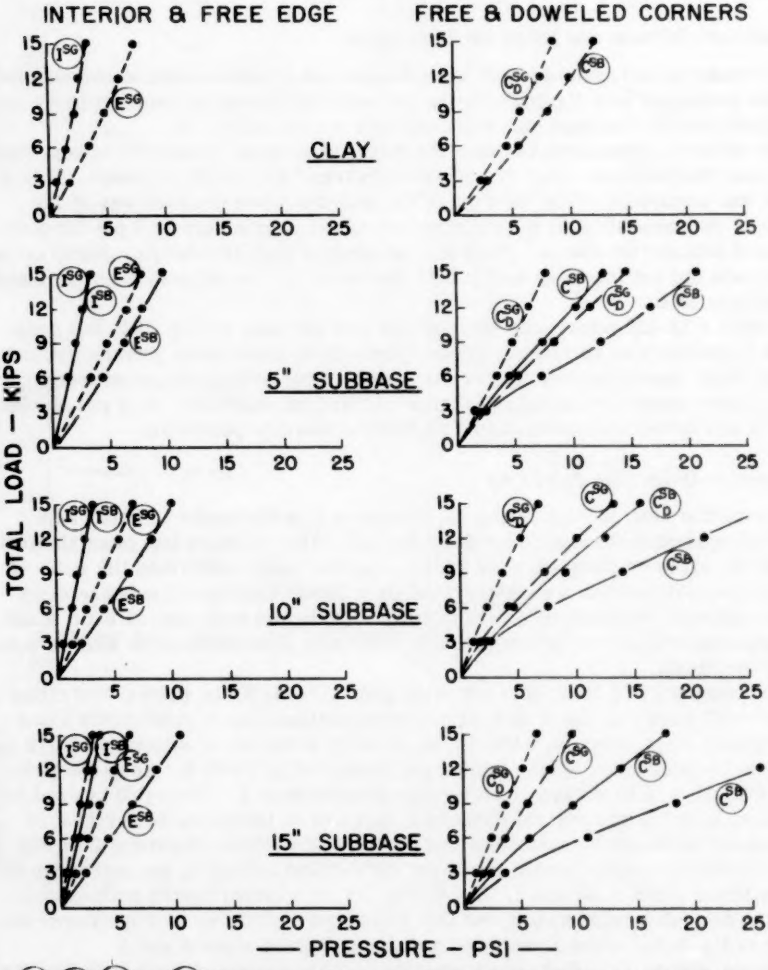
From the data of Figs. 9 and 18, pressure directly under the slab was plotted against deflection to produce Fig. 20. This relation has been studied(1) for 6-in. slabs on dense-graded gravel, and for those conditions the ratio of pressure to deflection was approximately a linear function of subbase thickness and was independent of load position. In the present case of 8-in. slabs on open-graded gravel, p/d appears to vary with load position as well as subbase thickness.

To compare p/d from slab test data with k from 30-in. plates, the ratios were read from Fig. 20 at deflection levels comparable to maximums found in highway tests, namely, 0.050 in. at corners, 0.025 in. at edges and 0.010 in. at interior positions. These values are compiled in Table 5. As in the previous study, p/d is always considerably greater than k. When p/d is used in place of k in the theoretical equations, there is no universal betterment of agreement between experimental and theoretical results. Equation 2 of Fig. 13 approaches the experimental curve for deflections of slab 1, but increases the deviation in slabs 2, 3, and 4. Eq. 4, Fig. 14, is a better match with experimental data when p/d is used, but Eq. 14 is poorer. There is some improvement in Eq. 6 for slabs 1 and 2 but a disadvantage in slabs 3 and 4.

Strain curves 1, 3, 5, 7, and 9 provide poorer agreement with experimental data when p/d is used instead of k with the 30-in. plate. However, the relation between the experimental curves and strain curves 10 and 13 are improved by the use of the p/d relationship. The conclusion is that k from the plate test is as good a foundation modulus to use in theoretical computations as any modifications that might be suggested from the p/d study.

Effect of Load Transfer Across Doweled Joint

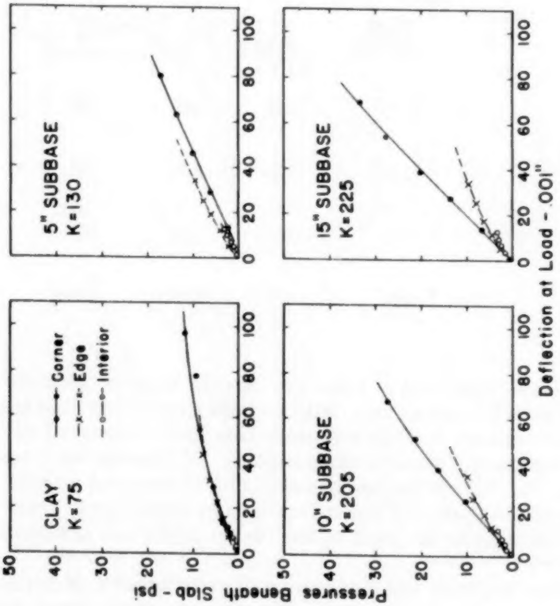
Loads applied at a doweled edge or joint cause deflections, strains and pressures which depend upon the efficiency of the load transfer system. In



(I^SB) (E^SB) (C^SB) & (C_D^SB) Pressure Directly Beneath Slab Under Interior, Free Edge, Free Corner, and Doweled Corner Loads, Respectively
(I^SG) (E^SG) (C^SG) & (C_D^SG) Pressure On Clay — Beneath Subbase

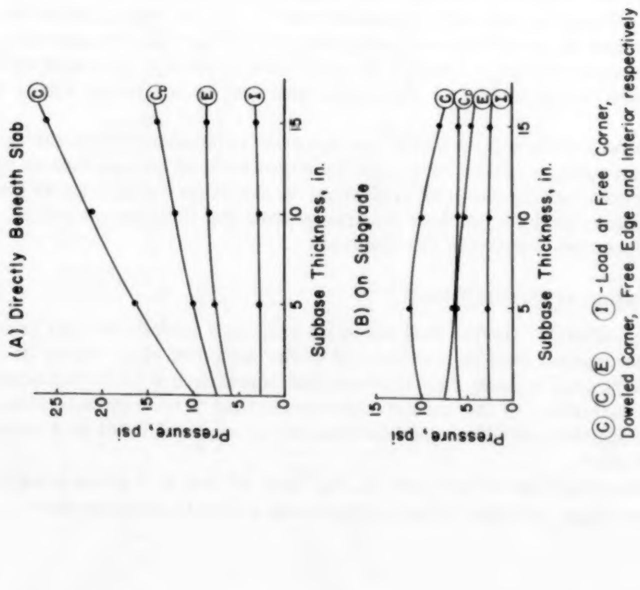
MAXIMUM PRESSURES BENEATH SLAB AND SUBBASE

Fig. 18



PRESSURE-DEFLECTION RELATIONS AT POINT OF LOADING

Fig. 20



PRESSURES DUE TO 12-KIP LOAD

Fig. 19

TABLE 5

PRESSURE-DEFLECTION RATIOS

	Ratio, pci			
	Clay Subgrade	Subbase Thickness 5 in.	10 in.	15 in.
k, 30-in. plate at 0.05 in.	75	130	205	225
p/d, Corner load at 0.05 in.	170	220	420	500
p/d, Edge load at 0.025 in.	220	300	460	500
p/d, Interior load at 0.010 in.	220	250	270	300

these tests the system was composed of 1-in. slip dowels at 18-in. centers through a 3/16-in. sheet metal separator. With an appraisal of the load transfer devices in mind, deflections, strains and pressures were measured on both sides of the joint during the static loading studies. Values on the loaded side were given in Fig. 10. Values on the opposite side of the joint were always less than those at the load, and the differences in deflections, pressures and surface strains across the joint at the 10-kip load level are shown in Fig. 21.

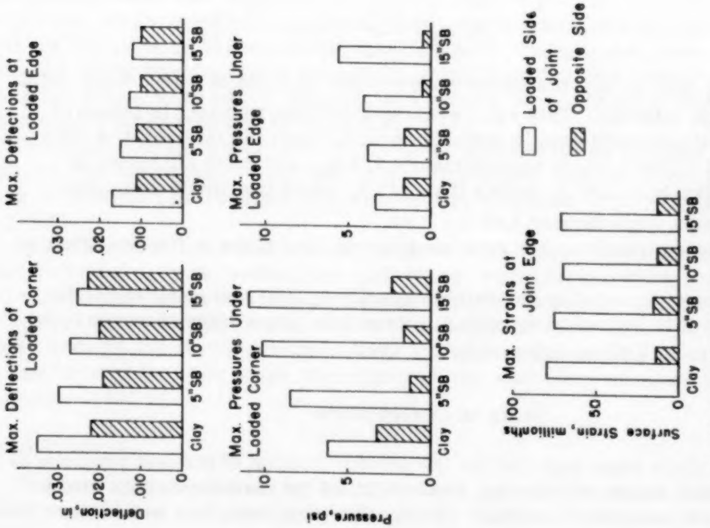
Due to instrumentation methods and limitations, it is believed that deflection measurements are more indicative of the effectiveness of the dowel system as a device for transferring load than measurements of pressure or surface strain. The pressure cell diameters are 7-1/4 in. and in order to reduce interference in operation, two adjacent cells at a joint are approximately 8 in. on centers. Thus, part of the pressure reduction indicated by two adjacent cells is due to lateral placement and part is due to the action of the joint.

Surface strains likewise do not indicate the true relationship between maximum stresses on opposite sides of a joint because the load on one side is applied through a distributing plate whereas that on the other is applied by the dowel. It is unlikely that the surface strains across the joint measured in this test are maximum strains in the concrete.

Performance Rating of Doweled Joint

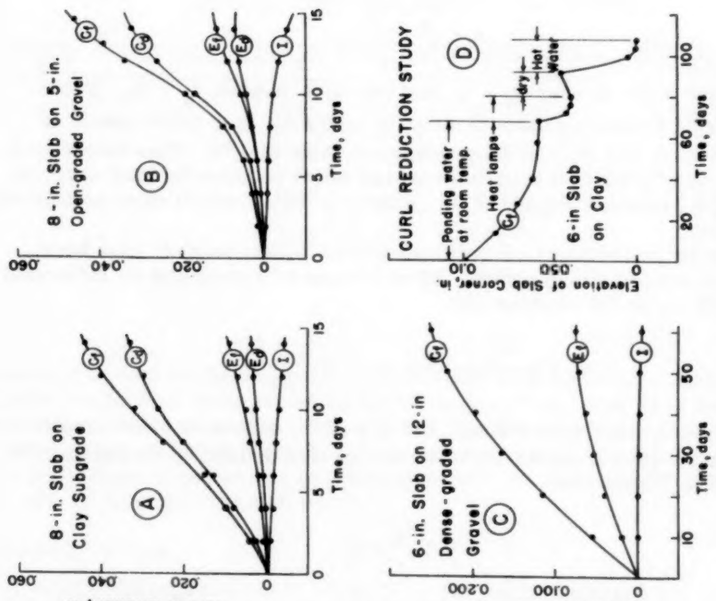
The best load-transfer device that could be built in a pavement joint is one in which half the applied load is transferred to the adjacent slab. Since deflection is proportional to load, this implies that when such a joint is loaded on one side the deflection of the loaded side equals that of the opposite side. Each deflection approximates one half that due to an application of this same load at the free edge.

An expression involving deflections d_i, d_e, and d_j due to a given load at an interior, free edge, and joint edge position may serve to indicate the



MEASUREMENTS AT DOWELED JOINT
10 KIP LOAD

Fig.21



C_f = Free Corner, C_d = Doweled Corner, E_f = Free Edge, E_d = Doweled Edge, I = Interior

SLAB CURLING

Fig.22

load-carrying capacity of the pavement at a joint relative to the capacity at an interior position. This rating is expressed as the "joint performance ratio"

$$R = \frac{d_e - d_j}{d_e - d_i}$$

which has the value 1 when $d_j = d_i$ and the value 0 when $d_j = d_e$. From Westergaard's formulas (Table 4) using $d_j = 1/2\, d_e$, it is found that R is independent of k and P, and has a maximum value of 0.70. Thus theoretically an "optimum" joint is a built-in weakness which reduces the load-carrying capacity of a pavement 30% below its capacity if the pavement were continuous and unbroken.

Methods for estimating joint "efficiency" and "effectiveness" have been proposed by several investigators. Effectiveness was computed by Teller and Sutherland(6) using the expressions:

$$E_1 = \frac{2d'_j}{d_j + d'_j} \quad \text{and } E_2 = 2\frac{(d_e - d_j)}{d_e}$$

where d_e and d_j have been defined, and d'_j is the deflection of the unloaded slab across the joint from the load. Efficiency was defined by Westergaard(5) by the symbol J such that

$$J = 1 - \frac{d_j - d'_j}{d_e - d'_e}$$

where d'_e is the deflection of the unloaded slab when no provision is made for load transfer.

Efficiency was also expressed by Teller and Sutherland as the stress ratio

$$E_3 = \frac{S_e - S_j}{S_e - S_i}$$

when S_e, S_j and S_i are maximum stresses due to loads at a free edge, joint edge and slab interior. This ratio evaluates the load transfer in terms of stresses, but interpretation is difficult because from the interior and edge equations of Table 4, S_i is approximately $2/3\, S_e$, and 100% efficiency is achieved when $S_j = 2/3\, S_e$ rather than $1/2\, S_e$ which one would anticipate when each joint edge carries half the load.

The above expressions are evaluated for the test slabs in flat condition in Table 6.

The effect of increasing foundation capacity is apparent in all methods except E_3. This is consistent with previous data which show stresses to be less sensitive to k than deflections.

Tests on Curled Slabs

The test slabs were kept flat for the greater portion of the test program in order that slab shape and bearing area would not be variables which would complicate the analysis of subbase effect. However, the slabs were later

TABLE 6
Joint Performance and Load Transfer Ratings

Rating Symbol	Rating for Indicated Subbase Thickness, in. 0	5	10	15	Optimum Value ($d_j = 1/2\ d_e$)
R	0.46	0.48	0.55	0.76	0.70
E_1	0.78	0.84	0.84	0.87	1.00
E_2	0.57	0.60	0.67	0.75	1.00
J	0.74	0.82	0.82	0.85	1.00
E_3	0.40	0.34	0.40	0.37	1.00 ($S_j = 2/3S_e$)

permitted to curl so that the performance under load might approximate that of slabs in the field when the edges and corners are curled upward due to differential moisture content or temperature. The curl induced in the slabs was the result of drying shrinkage of the upper surface. Moisture gradient was not measured and no analysis was made of restraint stresses induced in the slab by subgrade and slab weight.

Magnitude of Curl

Corners and edges of slabs drying from the top curl upward and remain at elevated positions unless forced downward by load or temperature. In Fig. 22, graphs A and B show the upward movements of corners and edges of 8-in. slabs and downward movements of the slab centers. About two weeks after the ponding water was removed, the corners were elevated over 0.04 in. All of the 8-in. slabs behaved in similar fashion when dried from the top so only data for the slabs on the sub-grade and on a 5-in. subbase are given. The rate of curling was dependent upon the ambient humidity, but corner elevations of 0.05 in. were easily attained, and usually the slabs were load-tested when curled approximately this amount.

The rate of upward movement of the 6-in. slabs in the first study (graph C) was considerably greater than that of the 8-in. slabs, and the increased time span of the first test resulted in a final corner elevation of 0.25 in. as seen in Fig. 22C.

Graph D, from data on a 6-in. slab, shows that corner elevation cannot be restored by simply re-wetting the surface. At room temperature, surface water reduced the corner elevation about 40%, dry heat accomplished another 20% temporarily but the drying action soon reversed the trend. Finally, hot water brought the corners down to their initial elevations. At the cessation of this treatment, after water was removed, the slab corners again raised to elevation 0.100 in.

Load Tests

The test routine outlined for flat slabs was repeated on curled slabs. All slabs were tested with similarity in results. The complete data for the 8-in.

slab on 5-in. open-graded sand and gravel are shown in Fig. 23. Differences in magnitudes of measured quantities from those measured for flat slabs at various loads may be computed by comparing Fig. 23 with Figs. 9, 10 and 11. The differences for a 10,000-lb load are shown in Fig. 24.

Lines representing equations 6, 9, 10, 13 and 14 have been drawn in Fig. 23 for comparison with theory. Kelley's Eq. 9, Pickett's Eq. 10, and Westergaard's Eq. 13 and 14 were developed for curled slabs and the experimental data are in good agreement with these curves. Westergaard's Eq. 6 is an original flat-slab curve and is presented here because no corner deflection equation has been developed for curled slabs.

As seen in the lower part of Fig. 23, subbase pressures under the edge, were approximately proportional to the applied load, but the corners showed a delayed response to increasing load increments. The load-pressure curve for the free corner changes slope rather sharply at a 6-kip load. The corresponding deflection curve shows that the corner had deflected about 0.04 in. when the break in the pressure curve occurred. This is reasonable in view of the fact that the elevation of the curled corner was 0.035 in. and no direct pressure was applied over the subgrade cell until the curling had been overcome. It may also be seen at the top of Fig. 23 that the strains became less per load increment when subgrade contact was made at a load of about 6,000 lb.

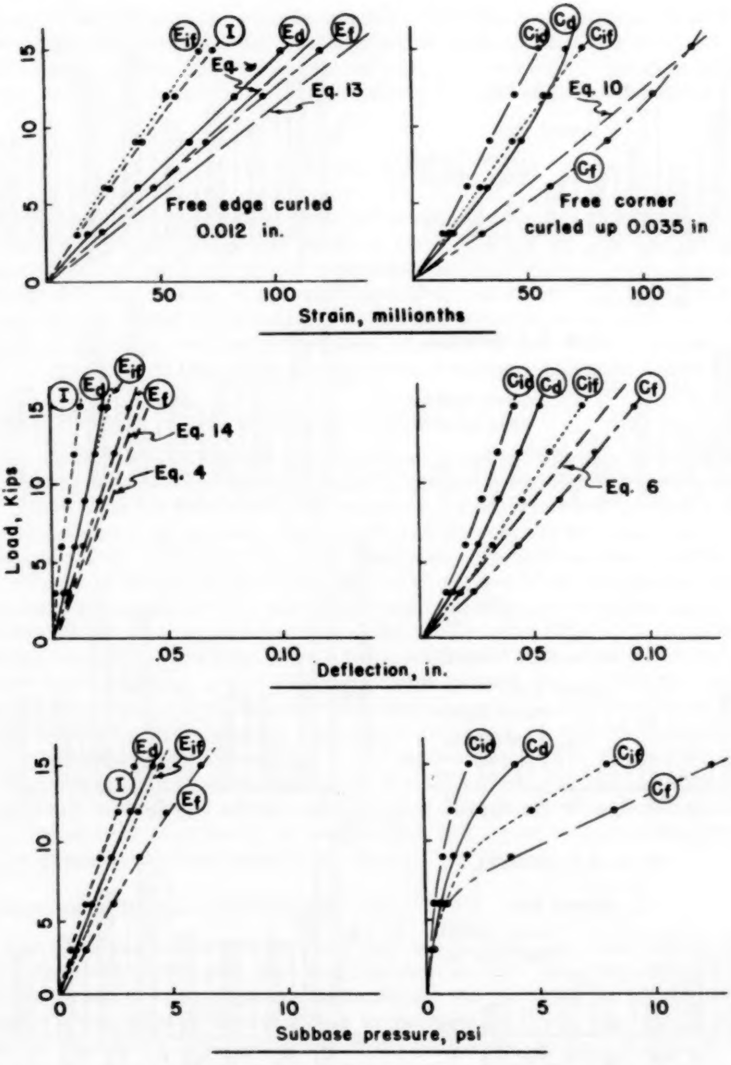
Since load-strain and deflection data for curled slabs on 0, 10, and 15 in. subbases were similar in character to those of Fig. 23 for a 5-in. subbase, a complete treatment of these data is omitted. A concept of the trends in strain and deflection magnitudes for slabs on other subbases may be had from Fig. 24 in which values are shown for a 10-kip load. For direct comparison, deflections and strains for flat slabs under the same loads are adjacent to the corresponding values for curled slabs.

It is seen that both free and doweled corners have considerably higher deflections and strains when curled than when flat. These differences vary considerably but it is not unusual to find curled-slab values 30 to 40 per cent above flat-slab values in these areas.

Edge deflections of curled slabs are slightly greater than those for flat slabs, and curled-slab edge strains are slightly less than flat-slab edge strains. This has been observed in other slab tests, both indoors and outdoors. The edge strains of curled slabs usually ranged from 5 to 15 per cent lower than the flat-slab values.

Effect of Load Position on Strain and Deflection

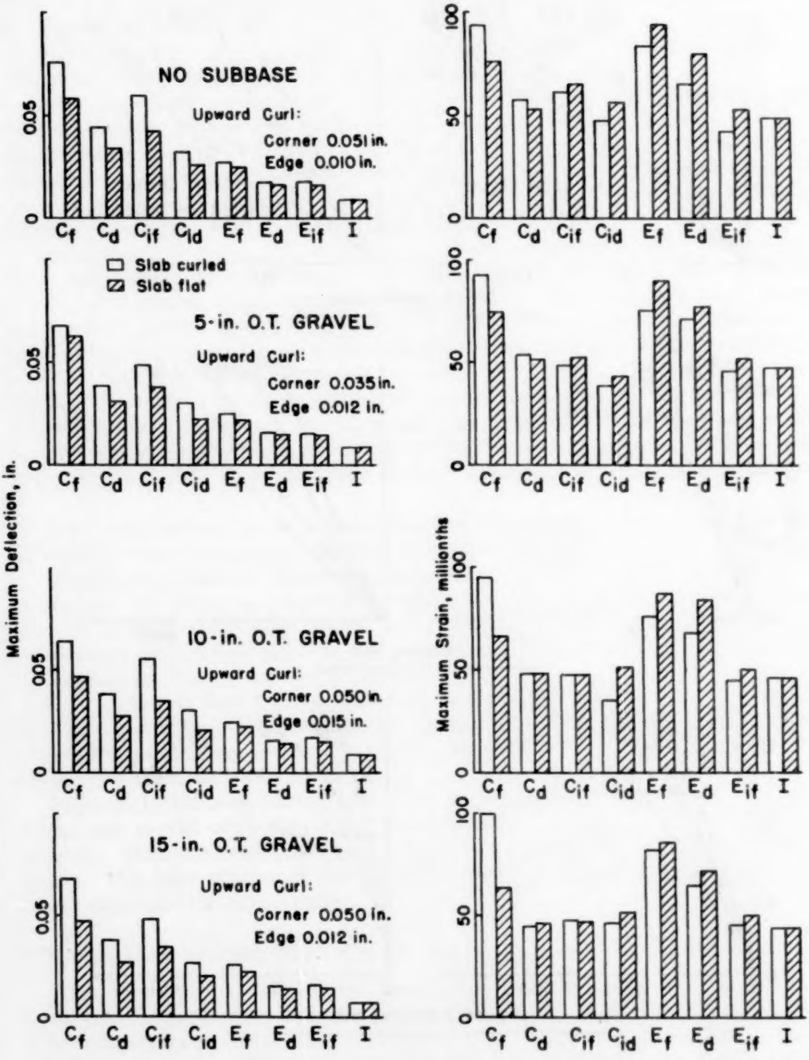
Fig. 24 clearly shows that for both flat and curled slabs, strains are higher near free corners, free edges and doweled edges, and deflections are high in the corner region. However, in all cases these relatively high strains and deflections can be greatly reduced by placing the load inward from the pavement edge. For example, in these tests, with the 12-in. load-plate seated one foot in from the edge (18 in. from center of plate to slab edge), corner and edge strains were held to values approximating those observed under interior loading. This is a very significant observation since current traffic surveys show that on present-day 12-ft wide traffic lanes, very few wheels travel within the outer foot of the pavement. Thus it becomes obvious that the wider pavements now being used not only contribute to safety, but also reduce pavement stresses due to load.



Load Position: I = Interior, E_f = Free Edge, E_{if} = Inward from Free Edge, E_d = Doweled Edge, C_f = Free Corner, C_{if} = Inward from Free Corner, C_d = Doweled Corner, C_{id} = Inward from Doweled Corner

Fig. 23 - STRAINS, DEFLECTIONS, AND PRESSURES FOR CURLED 8-IN. SLABS

5-in. Gravel Subbase



Load Position: I = Interior, E_f = Free Edge, E_{if} = Inward from Free Edge, E_d = Doweled Edge, C_f = Free Corner, C_{if} = Inward from Free Corner, C_d = Doweled Corner, C_{id} = Inward from Doweled Corner

10 kip load

Fig. 24 - DEFLECTIONS AND STRAINS IN FLAT AND CURLED SLABS

8-in. Slab

Only in one area do the strains remain relatively high regardless of the width of the pavement and the lateral position of the load. This is at a doweled edge, which may be considered also as a doweled transverse joint. Strains in this area will be evaluated more thoroughly in future studies.

SUMMARY AND CONCLUSIONS

Static loads were applied at different positions to a series of full-scale laboratory replicas of concrete roadway slabs to study the effect of thickness of open-textured sand and gravel subbases upon slab strains, deflections and pressures. Comparable tests were made when the slabs were kept flat to reduce the variables in the subbase study, and when the slabs were curled upward to simulate the prevailing shape of slabs as they exist in highways. For the condition of this study the following conclusions may be drawn.

Effect of Subbase Thickness on Load Capacity

The open-graded sand and gravel subbases under flat slabs were effective in reducing free-corner strains and deflections. Computations based on the test data and on the best fitting theoretical treatment showed that the free-corner deflection of an 8-in. slab on a 7-1/2 in. subbase would be about equal to that of a 9-in. slab directly on the subgrade. To accomplish a similar equivalence in corner strains, the 8-in. slab needed 17 in. of subbase. Edge load tests indicated that the subbases were less effective in reducing strains and deflections at this position than at the free corner (Fig. 17), and a 15-in. subbase had little advantage over a 5-in. subbase. These results show that unless thick subbases are required for frost control, the slight structural advantage of thick open-graded subbases could usually be achieved more economically by thickening the concrete. Generally, in frost-free areas the optimum subbase thickness is the 3 to 6 inches required to prevent pumping.

Comparing these results with those from a previous study on dense-graded sand and gravel subbases, it is seen that open-graded subbases under 8-in. slabs were less effective in deflection and strain reduction than the dense-graded subbases under 6-in. slabs.

Pressures on Subbase and Subgrade

The interface pressures between slab and subbase increased as the subbase thickness increased. However, pressures were distributed through the subbase layer in such a manner as to reduce the pressure on the subgrade slightly when subbase thickness was increased (Fig. 19). The tests indicate that the pressures on the subgrade in the field under an 8-in. slab on a granular subbase will be of the order of 5 or 6 psi at slab edges and doweled corners, and 2 or 3 psi at interior positions when the slabs are flat. Pressures under edges decreased when the slab was curled upward.

Effect of Load Position and Dowels on Strain and Deflection

Strains at slab edges and at free corners were greatly reduced when the load was applied inward from the slab edge. Dowels at joints also were effective in the reduction of strains in the corner region (Figs. 12 and 24). For a load one foot in from the edge, the strains at the edge or at a doweled corner

or a free corner were practically equal to those for a load at the interior of the slab. These observations on both flat and curled slabs are significant and show the importance of consideration of load position when calculating the effect of load repetitions in design of a concrete pavement.

Deflections at the corner were greatly reduced when the load was applied inward from the free edge of the slab. However, dowels at the joint were even more effective in reducing corner deflection than was the inward load position. A combination of dowels and inward loading gave corner deflections approximately as low as those observed when the load was applied at a free edge. (Figs. 12 and 24). When the slabs were curled, deflections due to corner loads were as much as 25 percent greater than for flat slabs. However, deflections for free edge loading were not significantly greater for curled slabs than for flat slabs.

Again, as in the case of strains, loads inward from the free edge of both flat and curled slabs developed edge deflections much smaller than those caused by loads at the edge. These reduced deflections prolong pavement life by reducing possible subbase densification and subgrade pumping where native pumping-susceptible materials are used.

Comparison of Experimental Results with Theory

Strains and deflections measured under interior loading were found to be slightly greater than those computed by theory. However, both Westergaard's original 1926 equations (1 and 2) and his 1947 equations (11 and 12) agree reasonably well with experimental results and may be used with confidence. His 1933 equations (7 and 8) do not fit the experimental data (Fig. 13).

At the free edge, experimental strains approximated Westergaard's 1947 equation (13) when slabs were flat, and Kelley's 1939 equation (9) when slabs were curled. However, as the strains at the edge are not greatly different for flat and curled slabs, equation (13) also checks edge strains for curled slabs (Fig. 14 and 23). Experimental deflections were less than theoretical for slabs directly on the clay subgrade and on the 5-in. subbase, but fell between Westergaard's 1926 and 1947 equations (4 and 14) for the thicker subbases.

Corner strains and deflections for flat slabs were in rather good agreement with Westergaard's 1926 equations (5 and 6), (Fig. 15). For curled slabs, however, experimental corner strains checked best with Pickett's 1946 equation (10), (Fig. 23).

Summary of Principal Findings

1. The first 5-in. thickness of open-graded granular subbase contributed more to the load capacity of a pavement than any subsequent 5-in. layer. At free corners where the subbase was most effective, an increase of 1 in. in slab thickness developed the same resistance to deflection as 7-1/2 in. of subbase. For developing the same resistance to strains, 17 in. of subbase was equivalent to 1 in. increase in slab thickness. A recommendation of 3 to 6 in. of open-graded subbase over pumping-susceptible soils in preference to thick subbase appears to be good structural practice when frost control is not a consideration.

2. Pressures on subgrades under 8-in. concrete slabs were rather insensitive to thickness of open-graded subbase and were of low magnitude, varying

from 2 to 3 psi at interior positions to 5 to 6 psi at edges when loads were comparable to those produced by highway truck traffic.

3. The appreciable reduction in edge stresses and deflections resulting from placing the load inward from the extreme edge suggests that, in addition to other advantages, wide traffic lanes, with a consequent reduction of wheel passes on the slab edge, contribute to extended pavement life. This factor should be evaluated for pavement design.

4. These tests indicate that the most practical formulas for the computation of stresses and deflections in concrete pavements due to loads are Westergaard's original 1926 equations for interior loads, his 1947 equations for edge loads, and Pickett's 1946 equation for stresses due to corner loads. Values computed by the 1933 equations are not corroborated by experiment.

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Journal of the
HIGHWAY DIVISION
Proceedings of the American Society of Civil Engineers

URBAN TRANSPORTATION PROBLEM[a]

Progress Report of the Committee on Urban Transportation
of the Highway Division
(Proc. Paper 1801)

ABSTRACT

Better transportation service is an urgent need of the American community. Cities must achieve a rational balance between essential modes of transportation, and the modern urban complex demands an areawide approach to the problem. Moreover, transportation planning must be more closely integrated with the broad economic, sociological and political factors involved in city and regional planning.

Better transportation service is recognized widely today as an urgent need of the cities of our nation.

The need is manifest even to the untrained observer in the congestion on our streets and in the filled-to-capacity parking facilities. Lack of adequate transportation service has spawned a condition commonly called "The Urban Transportation Problem."

Stated quite briefly, this condition is one of motor vehicle traffic increasing at a rate exceeding construction of new facilities to accommodate the movement while, at the same time, use of public transit is declining to a point where the capacity of existing facilities is only partially utilized.

The following pages contain thoughts and observations on the urban transportation problem as viewed by several members of the Urban Transportation Committee of the Highway Division of the American Society of Civil Engineers. Intended as a report of that Committee, this document attempts to set forth some of the important facets; to outline certain obstacles to solution of the problem; and to suggest the changing role the civil engineer must play in the quest for a satisfactory answer.

Note: Discussion open until March 1, 1959. To extend the closing date one month, a written request must be filed with the Executive Secretary, ASCE. Paper 1801 is part of the copyrighted Journal of the Highway Division, Proceedings of the American Society of Civil Engineers, Vol. 84, No. HW 3, October, 1958.

a. Presented at the February 1958 ASCE Convention in Chicago, Ill. by D. Grant Mickle on behalf of the Committee.

By the way of background, it is noted that since 1947, the nation's motor vehicle registrations have increased some 72 per cent and total mileage driven has risen to within a few percentage points of that figure.

In the face of spiraling registrations, travel mileage and population, public transit riding declined from a peak of 23 billion passengers in 1946 to less than 11 billion in a decade later.

The Characteristics of the Problem

Today two-thirds of America's population live and work in urban areas. This concentration of people and resources would not have been possible without the mobility and the supply lines afforded by low-cost and dependable transportation. But in most of America's burgeoning urban areas, street and highway traffic congestion now seriously hamper the rapid, continuous and flexible interchange of goods and services. Although there is quite general agreement that capacity must be added to urban transportation systems* to raise standards of service and reduce transportation costs, there are opposing views on how this should be accomplished.

While urban highway planning and construction are being accelerated by the 1958 Federal-aid Highway Act**, questions have been raised as to the wisdom of concentrating public funds on facilities for automotive transportation to the almost complete neglect of public transit. Some observers of the urban scene contend that only a modern public transit system—with carrying capacity many times that of freeways and needing no vehicle-storage space in the heart of the city—can meet existing and future passenger-movement requirements of an urban complex. Traffic congestion and parking problems will be solved, they contend, if urban populations are given fast, convenient transit service. Commuters particularly would be attracted to such service.

The fact that modern freeways are filled to capacity in peak periods almost as soon as they are opened lends support to the view that the supply of such facilities cannot catch up with demand. Peak hour congestion on some newly completed urban freeways leads even highway engineers to conclude that improved public transit service must be relied on to help in the twice-daily mass movements between home and work.

Critics of this position point to the shift from public transit to automotive transportation that has occurred since 1945 (when war-time restrictions on motor vehicle manufacture and use were removed) as ample evidence that Americans find automobiles better suited to their present transportation requirements.

These critics assert that automotive transportation affords comfort, convenience and flexibility which public transit cannot match. Public transit was developed and flourished before automotive transportation became generally available. Transit helped create mass origins and mass destinations in cities and, in turn, was sustained by them. Expansion of concentrated mass origins and mass destinations has now practically come to an end, especially in the larger cities. Automotive transportation has given people a wider choice of

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*What is here referred to is not a system in the sense of an organized single functional unit. It is a complex of systems, some parts of which have innumerable individual operators.

**Of the $25 billion of Federal funds authorized by Congress for expenditure on the Interstate Highway System, about half will be spent in urban areas.

places to live, work and trade. More and more of them are choosing to live in low-density residential areas of predominantly single-family homes well beyond the limits of central cities. Industrial plants and large department stores have moved to outer sections of the metropolitan area where land still is available in quantity for all their needs, including parking. Public transit cannot be adapted to serve economically the passenger transportation needs of modern metropolitan areas whose growth patterns are influenced so strongly by the availability of private automotive transport.

In summarizing the arguments cited above, it should be pointed out that no large city could survive with only one mode of transportation. The real question being debated is the amount of emphasis to be placed on one particular mode. Each has its limitations. Mass transit must have mass origins and destinations, and where these do not exist, or cannot be simulated, the private automobile has a distinct advantage.

On the other hand, freeways with the capacity necessary for private automobile transportation, require vast tracts of land for rights of way, complemented with additional space for storage. The decision to rely heavily on one mode or the other will be influenced by the present shape of the city and the shape it is expected to take in the future. Besides, there are questions which neither of the arguments adequately answers: How can better transit be provided? Will people use it if it is provided? Who is going to pay the cost?

Some of the Obstacles to Solution

There is a widely-held opinion that future improvements in transit service must be paid for in part from public funds. With very few exceptions, public transit systems, because of their generally poor earning records in recent years, have not been able to attract risk capital to finance construction or reconstruction. And since transit service is vital to maintain a strong central business district (whence a large percentage of a city's property tax revenue is derived) many proponents hold that a subsidy to transit service can be justified.

On the other hand, other transit authorities hold that attractive public transit service can be self-sustaining. At the same time, they add that costs to the mass transit user under a self-sustaining system probably would not be significantly less than for private automotive transportation.

Unfortunately, the kind of data required to resolve these differences of opinion are not available, hence the questions are debated largely in the realm of speculation. Although information is at hand on some of the more obvious costs, the total costs of constructing, operating, and maintaining alternative forms of transportation are not known. More research must be directed toward such determinations, more must be known about the public desires for transportation service—what motivates people in their choice of mode of transportation; more must be known about the ideal shapes of cities in relation to transportation.

Governmental Problems

Possibly even more formidable than the financial obstacles are those created by overlapping jurisdictions in metropolitan areas to improve transportation facilities. Uncoordinated planning and lack of clearly delineated lines of public responsibility and authority are serious handicaps to effective transportation development.

Transportation is not a problem that can be solved within the confines of small communities. Matters essential to proper transportation planning must be carried out on an areawide basis. Engineers engaged in transportation planning, construction or operation must increasingly coordinate their activities.

In large urban communities, transportation facilities may include rail carriers, air transport, and water-borne vessels as well as motor vehicles. All of these facilities may be used in the transportation of people and goods. While our committee is concerned primarily with motor vehicle transport, that concern is not to the exclusion of other modes; especially as they must all dovetail to provide an adequate and economical transport system.

Moreover, the transportation plan, though important, is only a part of the general city plan. The general plan includes land use; water, sewer, and power; recreation, education; fire and police; and health. Within the transportation plan is included highways, mass transit (local and suburban) truck terminals, truck routes, docks, warehouses, depots and market areas.

Relation to Economic Values

Although it always has been recognized that an adequate transportation system is essential to the growth and economic well-being of a community, recent investigations show that improved highways have a far greater impact on economic values than previously realized.

In numerous cities it has been found that values of property bordering new freeways increase faster while those of similar property in other areas may fall as a consequence; that industrial and commercial establishments in the proximity of a freeway may do a greater volume of business, while at the same time business along congested routes may increase when the traffic overload is diverted to other highways.

In both the planning and in the detail design phase of major highway development, the engineer should be cognizant of these facts.

Relation to Social Values

In developing a master street plan, many of the existing arteries may have to undergo major reconstruction, and many new streets or freeways will be required to accommodate the traffic demand. When planning such improvements, it is also desirable that the engineer consider how they can perhaps serve other useful purposes besides traffic movement.

For example, a new freeway might be routed through a blighted area, not only because of low cost of property but also to alleviate an existing social and economic problem. Also, freeways—and to a lesser extent, major streets—may foster amenities and efficiency by serving as boundaries and buffer zones between differing land uses, such as industrial and residential areas.

Again, provision must be made so that recreational facilities (stadiums, parks, beaches, amusement parks, theaters and museums, for example) are, wherever possible, adequately served by both private and mass transportation.

Acceptable principles of transportation planning and design, in conjunction with other considerations such as those already mentioned, should constitute effective guides for the choice of highway alignments, exit and entrance ramps, interchanges, bus turn-outs, and other characteristics of modern expressways. Freeways would function more effectively as important parts of the community transportation system and better meet the existing and

anticipated transportation needs of communities if such principles were employed consistently.

Of course, it is easier to assert that transportation principles are needed than it is to develop them and have them universally accepted and applied by highway engineers. Nevertheless, such principles are being explored constantly. At one time or another, everyone who considers the problem of urban transportation must ask himself, "What should a transportation system do? What should be expected of it?"

First, and quite obviously, it should provide a means for moving people and goods safely, freely and economically.

Second, it should provide a choice of mode. Regardless whether the system is oriented primarily toward one particular mode or another, a choice must be provided for the users who will make their own decision based on the individual needs and ability to pay. Aside from the question of mass versus individual transportation, the system must make provision for pedestrians and for commercial and industrial users.

Third, it should make the city a more attractive place in which to live. This can be done by defining the individual communities within the urban complex, and at the same time making them an organic part of it. These are not incompatible goals. A community can be defined without necessarily being isolated.

Finally, a transportation system must provide the means for fulfilling the needs and desires of the urban population within their ability to pay.

Traffic studies repeatedly have demonstrated that existing and anticipated home-to-work and work-to-home peak passenger movements on weekdays determine the required capacities of trunk line sections of urban transportation systems. Also, peak recreational travel on weekends control the required capacities of other considerable sections of urban transportation systems—in many instances the same sections as are controlled by home-to-work travel.

Observations on trunk line sections of highway facilities have indicated that a pair of expressway lanes, devoted exclusively to buses in peak morning and afternoon periods on weekdays,could handle almost as many people as a pair of rapid transit tracks. A pair of freeway lanes would be used intensively in peak periods and possibly just as intensively on weekends; while a pair of rapid transit tracks would be used largely in peak periods on weekdays.

Consequently, where trackage systems presently are available, they might be utilized economically if they could be improved in attractiveness and expanded in capacity. Where such trackage systems are not currently available, however, freeways more likely than not may prove more economical and flexible as mass transit facilities than would new rapid transit trackage.

If the highway engineer were required to treat freeways as part of a community's over-all transportation system, he would soon realize than an urban freeway system presupposes terminal facilities at, or within easy walking distances of, important destinations. He also would realize that a large central business district must provide for convenient circulation within the CBD, that all day long would deliver people within easy walking distances of important destinations, and also provide adequate off-street parking spaces.

Using these basic principles and the transportation system approach, the highway engineer can do a far superior job of designing and constructing modern freeways, than he can by merely applying the yardstock of low construction cost as a criterion. Indeed, lowest construction cost may turn out to be highest cost per transportation unit. Conversely, highest construction cost actually may mean lowest cost per transportation unit.

In addition to being a transportation engineer, the modern highway engineer must be a planning engineer, as well. The reason is this: the modern freeway, as an important part of community transportation systems, adds such substantial values to adjacent lands that progressive businessmen lose no time in putting those lands to more productive use. Freeways thus become economic forces for development or redevelopment of land.

While there has been a tendency to think of the urban transportation problem only in terms of the mass movement of people there are other significant factors. Urban transportation includes pedestrian traffic, the transport of goods and services, mass transit, passenger automobiles and the assembly and distribution of people and goods at terminal points. The movement of goods is becoming increasingly essential as more goods and services are required each year. At present each urban resident uses some 18 tons of raw materials annually. The movement of people has become more complicated as work hours have been shortened; more people are shuttling in and out of cities in shorter periods.

Streets and highways can be used not only to alleviate traffic but to develop and change the very character of cities. While in general the science of roadbuilding has not been adapted to the art of building cities, the fact remains that transportation can be a tremendous factor for good in this regard. Engineers will have to give more consideration to this in the future than they have in the past.

Although automotive transportation in metropolitan America offers flexibility and convenience to a unique degree, it contributes to serious problems such as congestion, uncontrolled spread of urban areas, failure of mass transit, and disruption and decay of established city patterns. Providing additional transport capacity alone is not the solution. A comprehensive approach must consider the intricate issues of public finance, urban government, urban planning and the changing pattern of urban living.

It is apparent from this brief report that much basic research is needed if a practical answer to the urban transportation problem is to be found. In addition to the questions already raised in this document, there are of course many, many more. Only research can supply the answers to such questions as these:

Can transit service be self-sustaining? If not, what should public policy be, to maintain it where needed and where it cannot be privately operated on a paying basis?

Can urban expressways be made to function as publicly acceptable and economical public transit systems, without trackage and its attendant additional right of way?

To what extent are the values of land adjacent to expressways affected in relation to areawide values?

What factors justify the construction of an expressway? a freeway? How frequently should such facilities be spaced?

How may a transportation system be rated—

for balance between modes?

for balance between street classifications?

for economic necessity?

The Committee on Urban Transportation will cooperate with other committees of the Society and other groups in supporting the research necessary to answer the many questions which arise in the process of finding solutions.

The Role of Civil Engineer

Traditionally, the civil engineer has been responsible for the design and construction of the physical facilities broadly embraced in city development and especially in those related to the transportation plan. He also has had a major part in shaping the over-all city plan.

By training and experience, the civil engineer is eminently qualified to collaborate and assist in the determination of suitable uses for land within the plan area. His experience in residential subdivision development; in layout and development of industrial plants; in design, construction and operation of water and sewer facilities; in design, construction and maintenance of streets, rail facilities, harbors, and docks all place him in a strategic position to advise on these matters as they affect the plan and welfare of the community.

Even though the engineer may occupy a dominant role in these matters, it is important that people of other skills and training also make their contribution to city development—such as the economist, the sociologist, the financier, the city planner, the educator, the fire and police authorities, and others.

The basic question is "What kinds of cities do we want in the future?" This is a difficult riddle. Most of the engineer's training has dealt with problems he could both formulate and solve with a high degree of exactness. He has not paid much attention to the broader economic, sociological and political factors and relationships, largely because he lacked methods to integrate these intangibles with the physical side of planning. Now for the first time it appears he may have found a way to overcome this handicap. It might be called "Operations Research Planning" and involves the application of advanced statistical techniques to bring these factors and relationships into focus on a mathematically measurable basis.

If future engineers are to understand fully the complexities of the urban transportation problem, embracing all the elements touched on here, it would likewise seem desirable to re-evaluate the training of the civil engineer. Does his educational process equip him to appreciate the social and economic aspects of the problem? Is he required to obtain some knowledge of the planners thinking? Certainly the civil engineer engaged in urban transportation should understand its important ramifications in related fields.

In its effort to help in the development of this understanding, the ASCE Committee on Urban Transportation has as its objective ". . . to aid in advancing knowledge relating to the administration, economics, planning, design, construction, and operation (including use) of the internal transportation facilities required for the functioning of metropolitan and urbanized communities."

Respectfully submitted,

Donald S. Berry
Nathan Cherniack
William R. B. Froehlich
Harold J. McKeever
Terry J. Owens
D. Grant Mickle, Secretary
Norman Kennedy, Chairman

Paper 1802 October, 1958 HW 3

Journal of the
HIGHWAY DIVISION
Proceedings of the American Society of Civil Engineers

NEEDS STUDIES ON A CONTINUING BASIS

R. E. Livingston[1]
(Proc. Paper 1802)

Necessity of Agreement on Basic Concepts

The original needs studies prepared by many of the state highway departments were undertaken on what has come to be known as a crash basis. Subsequent to World War II, the physical highway plant of the states had deteriorated to the extent that it became urgent to secure additional financing to undertake work which could no longer by delayed. From this urgency developed the crash programs of needs studies to gather the information which could be presented to legislative bodies for the enactment of legislation which would make available the required funds. It now appears that what was considered to be a one-time job, must be handled on a continuing basis so that the legislative groups and the general public may have information available, at all times, regarding the condition of the physical plant and the required expenditures to place it in a condition of efficiency at any given date in the foreseeable future.

If each state legislature is to be provided with the desired information and if this same information is also to be required by the national Congress for its use in considering the biennial federal-aid laws, it would be foolhardy to attempt to perform the work in any but a standardized manner. Further, it does not appear to be reasonable that many deviations from a standard method should exist if the engineering phases are handled in a proper manner.

If standardization is to be achieved, we must reach agreement on a number of basic concepts. These basic concepts would apply to the type and extent of record information which must be kept current on the inventory of the existing plant. In addition, we must have adequate cost records covering the types of construction which are involved in current contracts. Further, we must know how many breaks must be made in a cost information as those costs are related to the various systems of highways and urban and rural construction.

Just as we must come to agreement on the type and extent of record information, it appears inescapable that we must also concur on the elements of

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segregation in the estimates and the number of work items that will be used in preparing the detailed engineering estimates.

Presuming that agreement must be reached on the elements and work items to be used in estimates, it becomes immediately pertinent to evaluate the people or groups of people who will be involved in the use of the information. This, in turn, should enable us to determine what information is needed and then to decide on a uniform method of presentation. Unquestionably, engineers will be responsible for the preparation of the estimate. Equally without question is the fact that legislative committees generally will be the groups who will use the prepared information. This makes it necessary to maintain a continuing liaison between the preparing and the using groups so that no conflict will develop when the information is turned over for use. It is the opinion of the speaker that if this liaison is properly handled, the legislative committees will be perfectly willing to accept the judgment of the engineers as to the propriety of the form and content of the needs estimates. If the ultimate responsibility for the decision is then placed on the engineer, he must make sure that his estimates and the descriptions which accompany them are presented in language which can be understood by the layman.

What Yardstick Should Be Used to Determine Adequacy?

From this point on, I should like to pursue a rational argument for methods of procedure by posing questions and making a comparison of the common techniques in use and then by a preponderance of argument in favor of one or the other, to make it clear which line should be followed.

In order to determine the cost for any proposed highway improvement, we must first select a set of construction standards on which the engineering estimates will be based. Many states have adopted such standards based on projected traffic and the capacity of highways of known dimensional characteristics. Such standards are available in the manuals of procedures of the Bureau of Public Roads issued for use in connection with the 1956 Federal Aid Act. These standards have been reviewed and ratified by the A.A.S.H.O. It would appear, then, that there is no area for extended argument as to the type of road or highway which is to be built for any given set of conditions. It must be assumed that these standards, which are nationally accepted, represent the best judgment of our highway engineering groups. They can now be applied as the yardstick of comparison by which the adequacy of the existing highway plant can be determined. This determination would allow us to prepare estimates based on engineering characteristics which theoretically would give us a highway plant of a desired type.

A number of needs studies conducted have employed a so-called tolerable standard. Just as the term would imply, the construction standard has been modified arbitrarily to a point where the judgment of the concerned individuals has indicated that the limit of tolerability would be reached. It is hard to rationalize the acceptance of a highway facility that is tolerable, rather than desirable. To the speaker, tolerability implies that a certain number of accidents and deaths due to lack of desirable characteristics of the highway are to be accepted because building the desired facility is too costly. It may well be that the legislative bodies which deal with taxation problems should make this kind of a determination. It seems highly indefensible that the engineer should compromise his judgment of what is acceptable by stating that something less than that is tolerable.

A number of states, including that of the speaker's residence, use a sufficiency rating to determine which segments of highway are in a condition which would justify the programming of funds for construction. Where systems of this type are used, it is imperative that the guide which is used to determine adequacy be exactly the same as the standard which will be applied in estimating the amount of construction funds needed to bring the facility up to the desired standard. Basically, it is the theory of your speaker that we should not deal in double standards, but rather that we should use the single standard which is to be applied to the construction project as the basis of both the engineering estimate and the determination of adequacy.

What Are the Essential Elements of the Estimate?

The word "element," as used herein, refers to the basic components of a highway which should be separated in a cost estimate. In further explanation, the cost of the through-traffic road is desired by practically all administrative and legislative groups. This element of the through-traffic road would then be supplemented by building on top of it the other elements which will be constructed at specific locations. As an example, how much does an interchange add to the cost of a basic road? Similarly, are frontage roads required at a specific location and if so, how much do they add to the basic cost? It would appear that the methods used at the present time should be reexamined to determine how many elements actually do exist. The estimation of all highway projects should then be made in a manner which will provide cost records which will segregate these elements. Suggested by the speaker as a framework are the elements that have been cited as examples in the foregoing. As a possible addition, we might include bridges as an element because of the drastic cost effect that the building of bridges can have on the over-all construction of a highway.

What Work Items Are Logical and Essential?

The elements of an estimate will need to be broken down into work items so that we will be able to provide cost data essential to the preparation of statistical estimates. Later in this discussion, the speaker proposes to cover the experience in Colorado where estimates are prepared on a detailed plan as contrasted with those which are prepared from statistical bases. At this point, let me simply state I believe it would be highly necessary to segregate the highway elements into work items so that statistical estimates can be prepared with assurance that they will be realistic. The work items that are necessary are somewhat variable state to state, if they are used in complete refinement. By this I mean that if the cost of excavation, hauling, base course surfacing, top course surfacing, concrete, steel and each of the usual bid items are segregated, we would have the same variation in work items that exists in the construction specifications of the many states. On the other hand, cost indices are usually prepared by grouping the pay items in a manner which statistically develops costs by grouping of items or by selecting items which are representative of proper groupings. In order that each state may avoid a re-work of its cost data based on contract items, it would appear logical that the work items be grouped in such a way that they will develop the desired information and at the same time, reduce the amount of detail work

required. Suggested then, as appropriate work items are the following:

A. Right of Way.
B. Grading and Minor Drainage.
C. Base or Supporting Courses.
D. Wearing Courses.
E. Traffic Services, such as signs and stripes, guard posts, delineation markers.
F. Utility Adjustments.
G. Engineering Costs.
   1. Preliminary.
   2. Construction.

It would be desirable that these work items be supplied for each of the elements of the estimate so that we would be able to tell the right of way costs for frontage roads, for the through-traffic roads, the excess cost of right of way for an interchange and, similarly, to tell the cost of grading and minor drainage for these same elements.

With this array of highway elements and work items available, it would be possible to make any kind of a combination that logic might dictate. It certain particulars are requested which are not inherently available from the suggested combinations, we should state that the logical analysis and estimation of the highway does not reveal the requested information. As an example, it is highly important that the cement industry should know the number of barrels of cement in a given volume of highway work. On the other hand, our estimates will generally carry square yards of pavement as a basic item and it becomes a secondary responsibility of the cement industry to convert this figure to barrels of cement. Similarly, the people who supply aggregates convert the same pavement figure to cubic yards of aggregate.

Methods Used in Colorado

Permit me to outline quickly the method now used in Colorado to develop the amounts of money involved in meeting the needs of the highway system.

First, we have a basic inventory record in the form of a data sheet which graphically tells us mile-by-mile just what type of highway is in place. This data sheet indicates total width, shoulder width, pavement type, the width of traffic lanes, right of way, bridges, etc. It further gives us the location of all curves over three degrees, all grades over three percent, and the location and description of bridges and railroad crossings. It shows where speed zoning exists and even indicates the placement of no-passing zones. It further indicates the location of all fatal and nonfatal accidents for the biennial period prior to the current year.

A separate document which is correlated with the data sheet base gives us the sufficiency rating of each subsection of our highway system. This sufficiency rating is used in developing programs for any given period of the future. Here is a simple example of this application:

> We consider a road rated at 69 points as being immediately inadequate. We further know, from some ten years of road rating, that the rate of obsolescence which results from normal destructive forces, plus traffic growth, is about one point per year. Hence, if we wish to know which sections of highway will need replacement in the next ten years, we deduct

ten points from the current rating and all sections which then rate 69 or less are considered in the ten-year program.

The third item of record information which is kept current is a cost index. It is our opinion that each state should maintain a cost index based on its own experience. We find from comparing our own cost index with national cost indices and with those of the states in the West, that as many as ten points separate our own experience index from the national and from other states which would be presumed to have similar experience. Our own cost index is kept on a quarterly basis and includes bid items which account for better than 95% of the total cost of a highway. It is the conviction of the speaker that it might be possible to take needs study information and convert it from year to year by the application of a cost index. In this manner, a reinventory could possible be delayed to a biennial basis.

With the basic tools of reference I have described, it is not too difficult to undertake a complete needs determination. The data sheets can be compared with the construction standard and with the sufficiency rating to determine current adequacy. If there is need for reconstruction, the construction standard, plus the basic cost information on the various elements of the roadway, can be expanded to determine the cost of the needed facility.

This brief account is, of course, an oversimplification because there is actually much detail involved. Our geometric standards must be used in conjunction with an estimate of future traffic which is prepared on a statistical basis for each segment of the highway system and the geometric standards must also be applied to the terrain in which the road is to be built. Our present capability has been augmented by the use of a 650 IBM computer in the Department. For each road section in the State, we punch a card off the data sheets indicating the current geometrics and condition. If the condition rating drops the card out into the needs category, the projected traffic establishes the type of road to be built. The memory cylinder includes cost per mile by terrain types and the computation for the basic roadway is produced. In the meantime, separate cards for bridges and interchanges are introduced into the chain of computation at the selected sites and these are added to the basic cost of the roadway for the indicated section. The accumulation of these data give total costs for the section in question. Summation reports by roadway element and roadway type are then rather simply run.

Shown on the screen at the present time are the types of summation of data which are produced from the IBM runs. (Plates I and II.)

The slides are actually summation sheets which were prepared at the conclusion of the study made in compliance with the Federal Aid Act of 1956. A casual observation indicates the data shown would supply answers to practically any reasonable question that could be posed.

CONCLUSION

In accomplishing a needs study, it is usually well to try to anticipate the questions which will be asked and then to conduct work in a manner which will supply answers to the anticipated questions. This is similar to the lawyer's method of preparing his opponent's case first and then preparing his own case to give answers which it is presumed will be asked by the opposition.

Section 210 Project: Highway Needs Study

State of Colorado

STATE SUMMARY BY ROADWAY ELEMENT
(Amounts in $1,000)

ROADWAY ELEMENT	FAI	FAP	FAS	TOTAL FEDERAL AID	NFA-SH	TOTAL SH	OTHER RURAL ROADS	OTHER CITY STREETS	TOTAL STATE
Thru-traffic road									
Rural	203,617	762,603	501,481	1,467,701	48,368	1,516,069	711,529	- -	2,227,598
Urban	45,568	97,509	50,383	193,460	1,752	195,212	- -	462,067	657,279
Total	249,185	860,112	551,864	1,661,161	50,120	1,711,281	711,529	462,067	2,884,877
Interchanges									
Rural	48,126	211,978	64,160	324,264	6,921	331,185	- -	- -	331,185
Urban	13,924	11,877	5,724	31,525	- -	31,525	- -	- -	31,525
Total	62,050	223,855	69,884	355,789	6,921	362,710	- -	- -	362,710
Frontage road									
Rural	12,496	19,537	7,950	39,983	1,304	41,287	- -	- -	41,287
Urban	603	385	889	1,877	- -	1,877	- -	- -	1,877
Total	13,099	19,922	8,839	41,860	1,304	43,164	- -	- -	43,164
Climbing lanes									
Rural	- -	19,690	1,229	20,919	- -	20,919	- -	- -	20,919
Urban	- -	- -	- -	- -	- -	- -	- -	- -	- -
Total	- -	19,690	1,229	20,919	- -	20,919	- -	- -	20,919
Grand Totals									
Rural	264,239	1,013,808	574,820	1,852,867	56,593	1,909,460	711,529	- -	2,620,989
Urban	60,095	109,771	56,996	226,862	1,752	228,614	- -	462,067	690,681
Total	324,334	1,123,579	631,816	2,079,729	58,345	2,138,074	711,529	462,067	3,311,670

NOTE: On all Federal Aid systems and the Non-Federal Aid State system, the term "Urban" applies to only those areas established for incorporated places having a population in excess of 5000. City Streets, tabulated under the Urban category include all city streets other than State Highways regardless of the population size of the incorporation.

Section 210 Project: Highway Needs Study
State of Colorado
STATE SUMMARY BY WORK ITEM
(Amounts in $1,000)

	WORK ITEM	FAI	FAP	FAS	TOTAL FEDERAL AID	NFA-SH	TOTAL SH	OTHER RURAL ROADS	OTHER CITY STREETS	TOTAL STATE
RURAL	Right-of-way	11,439	170,756	92,286	274,481	9,946	284,427	1,134	- -	285,561
	Grading, drainage	82,852	453,068	294,700	830,620	27,240	857,860	335,620	- -	1,193,480
	Utility adjustments	684	5,439	3,054	9,177	257	9,434	- -	- -	9,434
	Surface and base	95,615	201,865	95,661	393,141	10,442	403,583	323,751	- -	727,334
	Shoulders	10,605	36,876	21,063	68,544	1,879	70,423	- -	- -	70,423
	Structures, over 20'	55,027	120,076	59,733	234,836	5,950	240,786	51,024	- -	291,810
	Number of structures	(673)	(2,582)	(1,550)	(4,805)	(139)	(4,944)	(1,713)	- -	(6,657)
	Roadside development	3,431	- -	- -	3,431	- -	3,431	- -	- -	3,431
	Traff. & pedestr. serv.	4,586	25,728	8,323	38,637	879	39,516	- -	- -	39,516
	Total	264,239	1,013,808	574,820	1,852,867	56,593	1,909,460	711,529	- -	2,620,989
URBAN	Right-of-way	9,186	55,565	28,968	93,719	891	94,610	- -	26,057	120,667
	Grading, drainage	12,546	13,142	8,749	34,437	244	34,681	- -	125,487	160,168
	Utility adjustments	209	395	272	876	3	879	- -	- -	879
	Surface and base	9,817	18,250	10,263	38,330	559	38,889	- -	263,018	301,907
	Shoulders	1,083	1,959	1,112	4,154	55	4,209	- -	- -	4,209
	Structures, over 20'	24,746	19,192	7,025	50,963	- -	50,963	- -	47,505	98,468
	Number of structures	(91)	(116)	(63)	(270)	(-)	(270)	- -	(190)	(460)
	Roadside development	1,247	- -	- -	1,247	- -	1,247	- -	- -	1,247
	Traff. & pedestr. serv.	1,261	1,268	607	3,136	- -	3,136	- -	- -	3,136
	Total	60,095	109,771	56,996	226,862	1,752	228,614	- -	462,067	690,681
TOTAL	Right-of-way	20,625	226,321	121,254	368,200	10,837	379,037	1,134	26,057	406,228
	Grading, drainage	95,398	466,210	303,449	865,057	27,484	892,541	335,620	125,487	1,353,648
	Utility adjustments	893	5,834	3,326	10,053	260	10,313	- -	- -	10,313
	Surface and base	105,432	220,115	105,924	431,471	11,001	442,472	323,751	263,018	1,029,241
	Shoulders	11,688	38,835	22,175	72,698	1,934	74,632	- -	- -	74,632
	Structures, over 20'	79,773	139,268	66,758	285,799	5,950	291,749	51,024	47,505	390,278
	Number of structures	(764)	(2,698)	(1,613)	(5,075)	(139)	(5,214)	(1,713)	(190)	(7,117)
	Roadside development	4,678	- -	- -	4,678	- -	4,678	- -	- -	4,678
	Traff. & pedestr. serv.	5,847	26,996	8,930	41,773	879	42,652	- -	- -	42,652
	Total	324,334	1,123,579	631,816	2,079,729	58,345	2,138,074	711,529	462,067	3,311,670

NOTE: On all Federal Aid systems and the Non-Federal State system, the term "Urban" applies to only those areas established for incorporated places having a population in excess of 5000. City Streets, tabulated under the Urban category include all city streets other than State Highways regardless of the population size of the incorporation.

There are limitations and they should be recognized. I have in mind that many of the studies on needs that are prepared make much of whether the needs costs involved are for highways on new or old location and whether the work proposed is considered to be construction or reconstruction. To those in the audience who have worked with this type of thing has come the realization that these descriptive terms are not as precise as they should be. As an example, in the Section 210 Study, relocation of 90% of a roadway was termed "old location" if the new highway occasionally infringed on the right of way of the old. Similarly, the line of distinction of what comprises construction or reconstruction can be argued for hours and no material increase in knowledge is achieved when the argument ends. The essential facts relate to how much it is going to cost to build the required highway plant. The categories of construction or reconstruction, new or old location, are somewhat beside the point. It is my firm conviction that we should develop a logical array of the elements of the highway plant along with the included work items. When the format for such an array has been established and applied for some several years, we may fully expect it will be accepted with little change by all people using it.

Paper 1803 October, 1958 HW 3

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COMPREHENSIVE TRANSPORTATION PLANNING[a]

Roger L. Creighton[1]
(Proc. Paper 1803)

ABSTRACT

An approach to transportation planning is examined, using as an example the work of the Chicago Area Transportation Study. Systematic methods are described for analyzing data and preparing and testing plans for all types of transportation facilities in urban areas, based on forecasts of traffic as generated by future land uses.

The purpose of this paper is to describe a particular approach to the study of urban transportation, called here "comprehensive transportation planning." The method of description will be by example, using as an illustration the work of the Chicago Area Transportation Study.(1)

Obviously, there is more than one approach to the study of urban transportation. At least four, somewhat overlapping, approaches can be named. There is (a) the approach of traffic engineering, (b) the "theoretical" approach, (c) the "special study" approach, and (d) the approach called "comprehensive transportation planning." Each of these approaches has its own merits, and is adapted to the solution of particular kinds of problems.

Traffic engineering, for example, is defined as "that phase of engineering which deals with the planning and geometric design of streets, highways, and abutting lands, and with traffic operations thereon. . .(2) This is an empirical approach, with a disciplined method, which looks at streets and highways from the viewpoint of what is happening on the street itself.

In contrast, the "theoretical" approach has its roots in operations research, in mathematics, and in computation equipment. It needs these tools

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a. Presented at the February 1958 ASCE Convention in Chicago, Ill.

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because the complex interactions of vehicles and persons in transportation systems cannot be studied by garden variety or do-it-yourself mathematics. Illustrations of this approach are the work of Wardrop,[3] who has developed a theory of route choice, of Lighthill and Whidham[4] whose studies of kinematic waves explain the nature of traffic tie-ups and of Prager,[5] who has extended Wardrop's theories into whole systems of streets.

The third approach might be called the "special study" approach. Examples of the extremely popular "special study" approach are the mass transit study, any origin-destination study which is limited to street and highway planning, and the parking survey. The disadvantage of this approach lies in the terms of its establishment: it was created to study just one particular aspect of transportation. While it may meet this need, its overconcentration generally will cause it to ignore other aspects, and this bias is dangerous for long-range planning and usually fatal to research work.

The fourth approach to the study of urban transportation is called here the "comprehensive approach." This approach has its roots in the "special study" approach, and it is a direct descendent of the origin-destination survey. It may include within itself the use of both the "traffic engineering" and the "theoretical" approaches. It may be defined as any very large study of urban transportation which:

a. deals with all forms of transportation in an urban area;

b. deals with a metropolitan area;

c. prepares a unified plan for several agencies;

d. systematically gathers, analyzes, and prepares plans from its own data;

e. seeks a deep understanding of the "why's" of urban traffic through its research;

f. uses a team of specialists from various professions and disciplines throughout its operations; and

g. considers land use planning and social objectives as well as transportation objectives in preparing its plans.

This last approach to the study of urban transportation is specifically designed as a tool for the planning of transportation systems and hence rates the highest, for this purpose, among the four approaches listed. When compared with the other approaches it is as the whole is to its parts – greater, and more complete.

Evaluated as an approach for research, comprehensive transportation planning also has advantages. The mass of data necessary for planning all forms of transportation is a mine of useful material for research. Secondly, the data manipulating capabilities of a large organization equipped with data processing machines eliminates many chores which impair the efficiency of individual research. Finally, there is a purposefulness within which results are prepared. This framework is frequently lacking in transportation research.

Comprehensive transportation planning is beginning to coalesce as an organized and systematic discipline. Rapid gains should be made in the next decade, partly because more research funds will be made available under the accelerated highway programs and partly because there are increasing pressures for better planning and for a metropolitan treatment of problems. The greatest gains will be made in the field of analysis and planning.

The Chicago Area Transportation Study

In 1953, the then largest origin-destination study was set up in Detroit, called the Detroit Metropolitan Area Traffic Study. The director of that study was J. Douglas Carroll, Jr., who is now director of the Chicago Area Transportation Study. The Detroit Study was not only the largest origin-destination survey yet made, but it was unique in one other respect: the whole operation, from data gathering through analysis to planning, was conducted by one team.

In 1955, representatives from the State of Illinois, Cook County, the City of Chicago, and the Bureau of Public Roads had begun negotiations among themselves to undertake a study, similar to but larger than the Detroit Study, for that area around Chicago included within a radius of about 30 miles from the Loop. Under the terms of the agreement which was reached, the four governments established the Chicago Area Transportation Study as an intergovernmental agency, to be administered by the Illinois Department of Public Works and Buildings, Division of Highways.

The purpose for establishing the Chicago Area Transportation Study was to develop a transportation plan for the Chicago area for a long-range (25 year) period. This transportation plan was to be comprehensive in these respects: (a) it was not to be for any single political jurisdiction, but for the functioning urban area of Chicago, (excluding Northern Lake County, Indiana); (b) it was not for highways alone, but for all forms of person and vehicular traffic (except railroad freight, long haul rail passengers, and air travel); (c) it was not limited to superficial examination and projection of trends, but it sought to obtain fundamental explanations for the causes of the generation and distribution of travel; and (d) it sought to integrate the work of a variety of specialists in transportation, city planning, and related fields.

The Study cost was estimated at $2,350,000, to be spent over the three-year life of the Study. Almost half of this sum was spent in the first year of operations, 1956, when the expensive data-gathering operations were in full swing. At peak employment, in August of 1956, over 360 employees were on the Study's staff. Since that time, employment and monthly disbursements have been steadily dropping, and will continue to drop until the Study ceases to exist at the end of 1958.

The valuable data which have been gathered will not disappear, however, when the reports are completed. A continuation of this work has been approved by the Study's Policy Committee. A continuing agency will have the responsibilities of maintaining data, supplying answers to specific short and long-range planning questions posed by the sponsoring agencies, and conducting basic research.

C.A.T.S. Study Design

One of the first duties of the Study staff, when it assembled in Chicago in late 1955, was to prepare a study design. The experience gained in Detroit was leaned upon heavily. The three major elements of this study design have remained essentially unchanged since that time. These elements are (a) data gathering, (b) statements of community objectives, and (c) a planning process. Each of these major elements is in turn made up of a series of minor elements.

Data gathering consists of three inventories. These are the inventory of land use, the inventory of travel, and the inventory of transportation facilities.

The second element of the study design - community objectives - is an explicit statement of the goals which should be achieved through the transportation plan. The comprehensive nature of the Study is demonstrated by the fact that these goals are not exclusively in terms of the movements of people and goods, but include standards of transportation service to land uses, of densities and community design, and of financial and economic objectives. The community objectives include, in short, a statement of the kind of city which the powerful influence of transportation should be used to achieve.

The third major element in the study design is a planning process, consisting of four parts. These are, first, a forecasting model which uses population and economic forecasts to predict the amount and distribution of land uses; second, a model which forecasts future traffic flows resulting from future land use; third, a designing process, and fourth, a testing process.

Data

In April of 1956, after nearly six months of intensive preparation, the data gathering operations of the Study were begun. These operations included three major inventories: the inventory of travel (April to November, 1956); the inventory of land use (July, 1956, to June, 1957), and the inventory of transportation facilities (November, 1956, to June, 1957). These inventories, with their necessary coding, checking, keypunching, machine checking, and other processing, consumed over half the Study's budget, or about $1,200,000.

The inventory of travel was composed of four surveys, designed to sample every type of travel within the Study area. These surveys included the home interview survey, the truck survey, the taxi survey, and the survey of external vehicles operating within the Study area (cordon line survey). One emphasis must be made: the home interview technique, because it records the travel patterns of every resident of a sample address, covers the usage of mass transportation as well as highway transportation, and thus makes comprehensive transportation planning a real possibility.

TABLE 1

INTERVIEWS, TRIPS PER INTERVIEW AND TOTAL TRIPS BY SURVEY TYPE, CHICAGO AREA TRANSPORTATION STUDY, 1956

(Figures are approximate)

Interview Type	Number of Interviews	Trips Per Interview	Sample Rate Expansion Factor	Estimated Total Trips	% Distribution
Home Interview	58,000	5.5	30	9,500,000	89%
Truck Survey	8,300	6.0	15	750,000	7%
Taxi Survey	150	40.0	30	180,000	2%
Cordon Line Survey	60,000	1.0	4	240,000	2%
	126,450	—	—	10,670,000	100.0%

Each of the 435,000 trip records obtained by survey (punched cards and tape records) contains information on the address of origin and destination of each trip (geographically coded to a half-mile coordinate system), trip

purpose at origin and destination, land use at origin and destination, mode of travel, travel time, parking, route of travel, and other data.

The second of the major inventories — the land use inventory — surveyed both land area and floor area. The land area survey, which measured the amount of land in each of ten categories of land use, has been completed for the 1,200 square mile Study area plus the northern part of Lake County, Indiana. The floor area survey was only conducted for the 300 square miles which had Sanborn map coverage, but this included all of the city of Chicago. The floor area survey measured floor area within 88 different categories of establishment types. These 88 categories are reconcilable on the first digit to the 10 land use categories. This land use survey is the largest as well as the most detailed such survey ever conducted.

TABLE 2

GENERALIZED LAND USE IN THE STUDY AREA OF THE CHICAGO AREA TRANSPORTATION STUDY
(Preliminary Data)

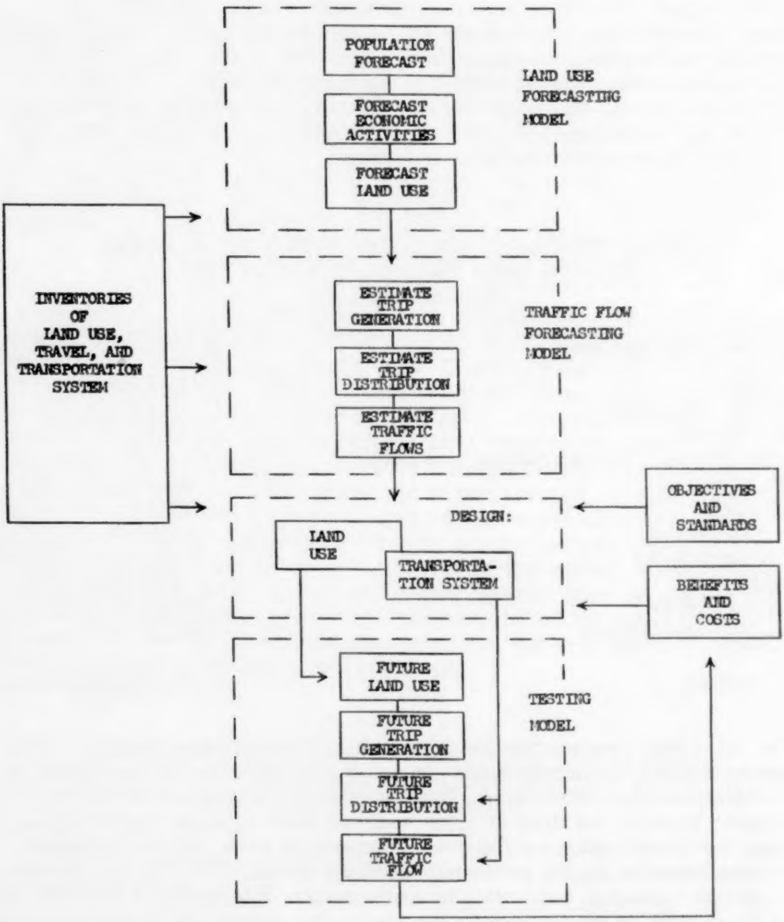
Land Use Classification	Area in Square Miles
Residential	181.5
Forestry, Fisheries	3.1
Manufacturing	24.9
Transportation, Communications, and Public Utilities	51.6
Commercial	21.3
Public Buildings	23.2
Public Open Space	115.6
Parking	1.7
Streets and Alleys	136.3
Vacant and Agriculture	677.5
TOTAL	1,236.7 Square Miles

The third major survey was the inventory of transportation facilities. This inventory coded 2,700 intersections and 4,700 routes between intersections in the 1,200 square mile Study area. Each intersection was described by its geographic location, the links or route sections entering it, its signalization, its type, and other features. The route sections, or links, between intersections were coded by length, by the intersections served, by width, and by route type, (whether arterial, boulevard, or expressway). Intersections and links of mass transportation facilities were included in the survey. With this coding system it became possible, either manually or by computer, to proceed from intersection to intersection through the entire network of transportation facilities, by any mode of travel, tracing and remembering the links of a journey between any origin and destination.

The Planning Process

The planning process of the Chicago Area Transportation Study is composed of four major parts, as shown in FIGURE 1. These four parts are the

FIGURE 1



BLOCK DIAGRAM OF STUDY DESIGN FOR CHICAGO AREA TRANSPORTATION STUDY

land use forecasting model, the traffic forecasting model, the designing process, and the testing model.

The land use forecasting model is the first step in the planning process. This model consists of three elements:

1. Predicting population.
2. Predicting the economic activity of the area.
3. From population predictions and from economic activity predictions, predicting the distribution of land use within the area.

The land use forecasting model begins by feeding the Study's population forecast into a model for forecasting economic activity. This model is a sequence of steps which proceeds from population, to income, to consumption, to the production needed to supply that level of consumption, and finally to the number and kind of workers needed to provide such a level of production. The predicted employment will then be checked against the original population forecasts and the whole checked against independent national and industry-type economic forecasts.

At this point, the Study will have in hand estimates both of population and employment by industry type through the year 1980. On this basis, the total amounts of land needed for future residential and non-residential activities can be determined. These total amounts of land must then be distributed among the 600 analysis zones comprising the Study area. This distribution will be a process of allocation of activities to analysis zones, in proportion to the amount of available land and in proportion to the attractiveness of each zone for the use being allocated.

The Traffic Flow Forecasting Model

The traffic flow forecasting model is another three-step process, consisting of the following steps:

1. Predicting trip generation.
2. Predicting trip distribution.
3. Estimating traffic flow.

The future distribution of land use for the target year of 1980 has now been made available. How many trips will this future land use generate? The answer lies in the relationship between land use and trip generation.

Taking the central business district of Chicago as an example, preliminary data indicate that about 457,000 trips are made each day to this one square mile area by residents of the Study area. Measurements of buildings indicate that there are 85,790,000 square feet of floor area in this square mile.

The trip generation rate of floor area in the Loop then averages about 5.3 trip origins (or destinations) per thousand square feet per day. If external trips are added, this figure may be boosted to 6.0 or 6.5 trips per thousand square feet. In terms of net acreage of land (excluding streets) trip generation in the Loop is about 1200 trips per acre.

Similar trip generation rates, stratified by type of land use and controlled by densities, can then be used, albeit with some care, against 1980 land use to provide estimates of 1980 trip generation for each of the 600 analysis zones in the Study area. A table of trip generation rates using Chicago data is shown to illustrate the nature of these rates.

TABLE 3

AVERAGE WEEKDAY NUMBER OF PERSON TRIPS PER ACRE BY LAND USE BY DISTANCE RING FOR CHICAGO, 1956(6)

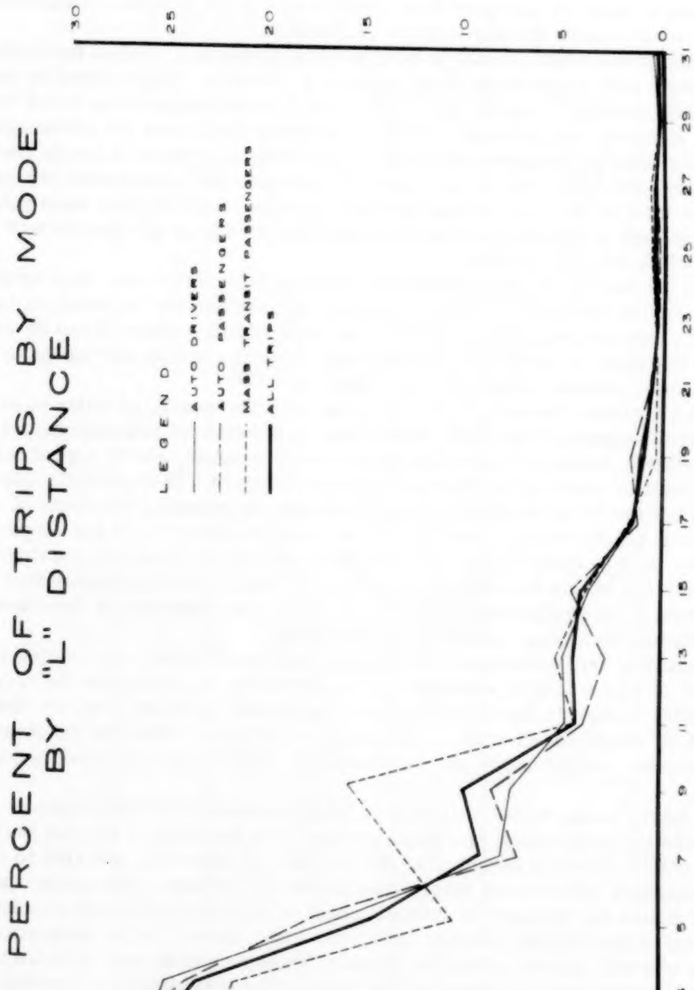
Distance Ring	Approx. Distance from C.B.D.	Internal Trips Per Acre of Land in Use — Land Use Type: Residential	Commercial	Manufacturing	Transportation	Public Building	Public Open Space	Total Land in Use
CBD	0	2120	2096	3343	265	1910	121	1149
I	1.5	213	182	229	36	241	31	142
II	4.1	123	118	78	15	120	25	90
III	6.1	104	141	85	11	97	27	85
IV	8.6	66	208	50	13	76	14	65
V	11.7	42	176	26	5	56	6	36
VI	15.8	30	129	14	2	45	2	19
VII	23.4	19	122	14	6	13	1	13
Total		47	177	47	8	51	4	37

As a result of the preceding calculations, the amounts of trip origins and trip destinations will be known for each analysis zone. The next problem is to estimate the connections between origins and destinations.

There are two classes of methods for predicting zonal interchange, the problem of linking origins with destination. The first class ("growth factor" methods) includes methods where known (1956) zonal interchanges are expanded selectively in proportion to the projected growth in trip generation of each of the analysis zones in the Study area. The second class of methods ("independent" methods) does not use 1956 zonal interchanges, but estimates zonal interchanges solely on the basis of the comparative attraction of each zone in relationship to all other zones and in some inverse proportion to the difficulty of travel between zones. Difficulty of travel can be expressed in distance, time, or cost. The regularity of distance as a factor reducing trip frequency is illustrated in FIGURE 2.(7)

Both classes of methods have their advantages and disadvantages, and are extremely complex technical processes, especially when it is realized that for 600 analysis zones in the Chicago Study area the number of possible non-directional interchanges is about 180,000. Nevertheless, sufficient advances are being made in both types of estimating procedures so that the Study should be able to predict 1985 trip interchanges reasonably accurately.

Once the zonal interchanges have been estimated for the target year, they must be translated into actual flows on streets and mass transportation facilities. It is only when zone-to-zone movements, expressed abstractly in the form of trip desire lines, have been converted into predicted loads that the true effect of the growth and change of the structure of an urban area on its transportation networks can be studied.


PERCENT OF TRIPS BY MODE
BY "L" DISTANCE
LEGEND
AUTO DRIVERS
AUTO PASSENGERS
MASS TRANSIT PASSENGERS
ALL TRIPS
PERCENT OF TRIPS
TRIP LENGTH IN MILES
0
5
10
15
20
25
30
1
3
5
7
9
11
13
15
17
19
21
23
25
27
29
31

Techniques for assigning zonal interchanges to the transportation network and predicting flows on those networks are being developed. This is another extremely complex technical problem: the maximum possible 180,000 zonal interchanges must be assigned to a network where the possible combinations of route choice move quickly into the millions.

One technique which seems to hold much promise is a method for finding the shortest path between pairs of points in a network. This method is based on work by Dantzig[8] and by Moore.[9] It is a notational system which can find the shortest path through a maze or network, and it has the advantage of being adaptable to computer operation. For small problems it can be done rapidly by hand. The use of this algorithm permits the assignment of trips from one zone to all other zones onto the minimum path between each pair of zones and then at the conclusion of this process to add up the numbers of trips using each link in the network.

Given the number of trips which are used on each link it will then be possible to modify travel times in accordance with the volume of travel on each link. For this purpose, the Study will use relationships which it has developed through the study of speed and volume conditions in Chicago during the inventory of transportation facilities. (see FIGURE 3)[10]

After the travel times on each link have been increased, in order to account for the usage of that link, it will then be possible to reassign all trips to the network, using the minimum path algorithm again, and to repeat this process until a state of equilibrium has been reached. Theoretically this equilibrium has been reached when no traveler, by changing his route of travel, will be able to decrease his travel time between origin and destination. Naturally, in a project of this size, the Study will have to satisfy itself with an approximation of this theoretical condition. It should be emphasized that this description of an assignment procedure is still in the process of development and is subject to further change and refinement.

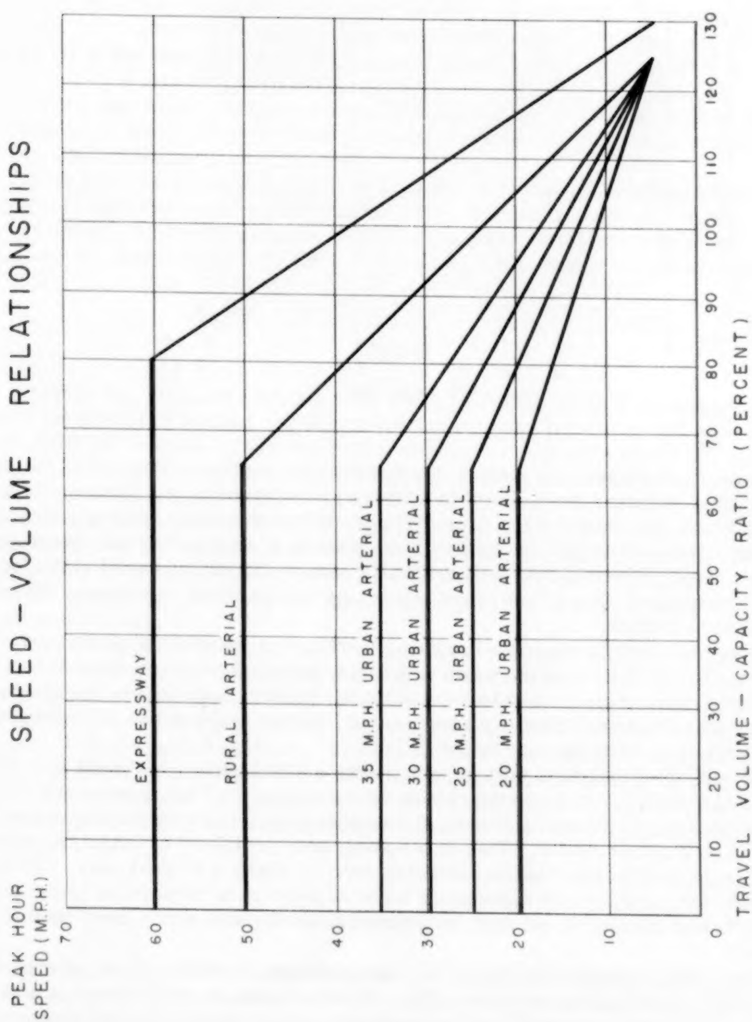
Forecasting trip generation, estimating trip distribution, and making assignment of future traffic volumes to transportation networks are the three parts which comprise the traffic forecasting model. In each case, the data obtained by interview will play a significant role in providing the constants and exponents, the formulae and relationships, which make the models possible.

How future urban travel will be distributed between different kinds of transportation is a crucial problem, because it is the Study's aim not only to predict traffic volumes on arterial streets and expressways, but also to estimate passenger volumes on mass transportation systems. Estimating the mode of travel can be handled either as part of the trip generation problem or as part of the trip distribution problem. Many limits fix the proportion of persons who will travel by auto or by mass transportation, and so there is confidence that close estimates can be made. The distribution of internal (home interview) trip origins by mode of travel shown in FIGURE 4 is indicative of the regularity and predictability of mode distribution.[11]

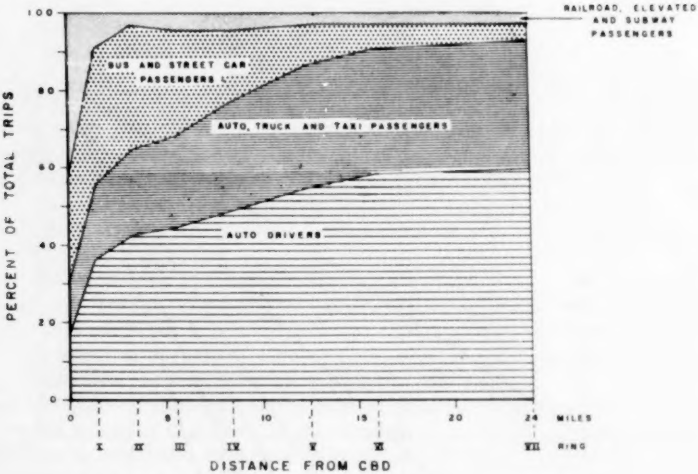
Another problem is the prediction of truck traffic and the prediction of external traffic. The methods generally described for estimating internal traffic to 1985 can also be applied to solve these problems.

The Design Process

The Study has been trying to put the design of a coordinated transportation system on the same logical basis as its forecasting work. There would be


SPEED – VOLUME RELATIONSHIPS
PEAK HOUR SPEED (M.P.H.)
70
60
50
40
30
20
10
0
EXPRESSWAY
RURAL ARTERIAL
35 M.P.H. URBAN ARTERIAL
30 M.P.H. URBAN ARTERIAL
25 M.P.H. URBAN ARTERIAL
20 M.P.H. URBAN ARTERIAL
10
20
30
40
50
60
70
80
90
100
110
120
130
TRAVEL VOLUME – CAPACITY RATIO (PERCENT)

PERCENT OF INTERNAL TRIP ORIGINS
BY MODE AND DISTANCE FROM C.B.D.



little profit in organizing a study design with extraordinary care if, at the last moment, a designer were asked to prepare plans based on his personal ideas of what would be best for the area. The Study has therefore fixed a policy of setting limits which will be applied successively to narrow the choices which can be made. These limits will gradually reduce the choices until only a very small number of alternative plans — perhaps two or three — remain. These can then be tested.

The first limit is the presence of an existing transportation system consisting of arterials, expressways, and rapid transit facilities. All of these facilities, plus some in an advanced state of construction, impose severe restrictions, since they represent huge capital investments, made over decades. Certainly they must be used to the fullest.

Second, there exists a city in being, with another huge investment in buildings and utilities. Part of this city is deteriorating, and many parts are changing their functions; the central business district, for example, is losing ground as a retail center. This poses some nice problems of balancing the construction of transportation facilities against changes in land uses. Nevertheless, the existing city represents from 50 percent to 70 percent of the city of 1985, and service to existing land uses is one demand which must be fulfilled.

Third, the standards to which the transportation system will be constructed exercise a great influence on the plan. These standards, written out in a design manual, will cover not only geometrics and capacities, but speed standards, standards of accessibility to expressway and mass transportation facilities, land planning standards, access standards, and so forth.

Behind these standards exist policy questions of great importance. Should residential land be developed at high densities? Should mass transportation be subsidized or allowed to die a lingering death as the city converts to higher

automobile usage? Should the central business district remain the dominant focus? Are there particular parts of the metropolitan area whose development should be encouraged ahead of other parts? All these matters must be decided with the utmost care, because the decisions reached will so directly influence the final design.

Fourth, the planned or forecasted pattern of urban land uses in the target year, together with the traffic volumes which these land uses will inevitably generate, will affect the design. This input to the design process may come either from the land use forecasting model described earlier, or from a plan developed by a city or metropolitan planning agency.

Finally, the relationships between benefits and costs, and the ability of the metropolitan area to pay for transportation, must be included as a limitation on the transportation plan.

These and other elements, will be worked over time and time again until a system of highways, expressways, arterials, bus lines, and rapid transit lines is developed which will meet the objectives and the standards which have been set, and will serve the needs for transportation throughout the period ending in 1980.

Testing

Whether the particular traffic plan which is developed is a good one or not still remains to be proved. In any designing process (including the preceding one) different persons would come up with similar, but not exactly the same, plans. Which of these plans is the best? This is a crucial problem, especially from a sales point of view. When a hydraulics engineer has finished his calculations he can say with certainty that water will be supplied in such and such quantities and at such and such pressures under such and such conditions in any part of his distribution system. If a transportation planner can make similar statements then he is in an excellent position to defend the correctness of his plans.

The testing process which the Chicago Area Transportation Study proposes to use is essentially the same as the traffic forecasting model. A future land use projection (which can be any hypothetical pattern) is fed in, resulting in a certain pattern of trip generation. These trips are then distributed and assigned to the proposed network. The traffic flows and mass transportation volumes on the proposed network are the outputs. If the system is overloaded or uneconomically underloaded then the design is found not to be satisfactory. It must be reworked until the testing shows that a good solution has been achieved.

CONCLUSION

There are a number of approaches to the study of urban transportation, each having its particular capacities to handle certain problems. If one is trying to prepare a long-range transportation plan, then the approach called "comprehensive transportation planning" in this report seems to have the best qualifications, for it plans for all forms of transportation, and it seeks as a basis for its planning work the deepest kind of understanding of the forces behind traffic.

While "comprehensive transportation planning" is not as mature as the older techniques of engineering design, it is beginning to have an organized and systematic way of attacking its particular problems. This is coming to be increasingly true for the analysis and planning phases, which have not been as well developed as the data gathering processes.

Organization in forecasting and planning, as represented by a carefully thought-out study design, is most essential. The kind of data to be gathered should be limited to only that which the study design shows is essential. The work of specialists from different disciplines must be integrated. A series of forecasts must be made, one dependent on the other, but carefully checked throughout. Standards for design must be prepared. Plans must be based on forecasts of future demand for travel, on standards, on existing land uses and transportation facilities, and on abilities to pay. Then the plans must be tested. All these things must be woven into a continuous fabric.

There are sufficient regularities in the generation and distribution of traffic so that the design of transportation systems is susceptible to the kinds of systematic processes which have been described. Beneath a rather baffling surface complexity there seems to be a basic order. When this order is thoroughly understood, then transportation planners should be able to justify and document their proposals with much the same certainty that engineers stand behind their designs.

The development of systematic problem-solving methods does not, however, mean that transportation plans can be evolved on a purely technological basis. An understanding of cities, of activities taking place in three dimensions, and of an urban society is necessary, together with some conception of where that society should go and of what forms the city should take. This understanding is part art, part philosophy, and part politics. Whatever its name, it is not a substitute which comes into play when the limits of technology have been reached, but rather a partner with technology is preparing solutions to one of the most difficult problems of our time.

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Paper 1804 October, 1958 HW 3

Journal of the
HIGHWAY DIVISION
Proceedings of the American Society of Civil Engineers

NEEDS OF THE INTERSTATE SYSTEM OF HIGHWAYS[a]

G. M. Williams,[1] M. ASCE
(Proc. Paper 1804)

SYNOPSIS

Provisions of the Federal-Aid Highway Acts from 1916 through 1956, the actions leading to establishment of the Interstate System of Highways in 1944, and plans for accelerating the rate of construction are reviewed. Brief data of mileages and costs derived from first of five estimates is presented.

Knowledge of the history of the growth and development of the highway transportation network now in existence in the United States—which network benefits in some measure every inhabitant of our nation—is necessary if one wishes to evaluate the plans now being carried out to make our highways adequate for the foreseeable transportation needs of our increasing population.

An inscription on the National Archives Building in the city of Washington reads, "What is past is prologue." For those who care to review a short prologue on highway transportation, two references are recommended. One is a publication of the American Association of State Highway Officials titled "Public Roads of the Past—Historic American Highways." Another is a publication of the Public Roads Administration (1949) titled "Highway Practice in the United States of America." Beyond these references is a library of reports, Congressional hearings and legislation.

What we are to review today is very recent history. Namely, some of the principal events that have taken place since the Congress, on July 11, 1916, under the provisions of Article I of the Constitution, enacted legislation "To provide that the United States shall aid the States in the construction of rural post roads. . ." The 1921 amendment to this basic Act put into effect the

Note: Discussion open until March 1, 1959. To extend the closing date one month, a written request must be filed with the Executive Secretary, ASCE. Paper 1804 is part of the copyrighted Journal of the Highway Division, Proceedings of the American Society of Civil Engineers, Vol. 84, No. HW 3, October, 1958.

a. Presented at the February, 1958, ASCE Convention in Chicago, Ill.

1. Asst. Commissioner for Engr., Bureau of Public Roads, Washington, D. C.

concept of integrated highway transportation systems of limited extent, to be selected by the State highway departments subject to approval by the appropriate agency of the Federal Government, which agency has been and is the Bureau of Public Roads, now included in the Department of Commerce.

Pertinent excerpts from the 1921 Act are, ". . . in approving projects to receive Federal aid. . . the Secretary . . . shall give preference to such projects as will expedite the completion of an adequate and connected system of highways interstate in character." ". . . such State, through its State highway department, shall select or designate a system of highways not to exceed 7 per centum of the total highway mileage of such State as shown by the records of the State highway department at the time of the passage of this Act." "Upon this system all Federal aid apportionments shall be expended." "The Secretary . . . shall have authority to approve in whole or in part the systems as designated or to require modifications or revisions thereof."

Under this legislation a Federal-aid highway system was designated and with the continuing assistance of Federal-aid financing during the 1920's and 1930's the State highway departments had accomplished the objective of constructing a system of two-lane roads connecting the centers of population. But our highway system was far from adequate. Increases in population, in the numbers of motor vehicles and the usage of each vehicle, raised the daily traffic flow on the constructed highways to a level above their safe and economical capacity. The result was higher-than-necessary transportation costs due to waste of fuel, loss of time, excessive wear on equipment from low type surfaces, high maintenance expenditures on obsolete highways, and a high human and property loss through motor vehicle accidents. The need for highway improvement on a scale larger and broader than had been accomplished became evident.

In this situation the Bureau of Public Roads saw a need for comprehensive studies to determine the conditions of the highways of the nation, the character and extent of their use both then and in the future, the source of funds for different classes of highways, and how the costs for highways were distributed among classes of highway users and other groups. These data were needed to establish what would be a definite, economically and socially defensible, integrated highway improvement program in all States.

The Congress, in 1934, under the Hayden-Cartwright Act made provision for such studies. That Act provided that not to exceed 1-1/2 percent of the Federal-aid funds apportioned to any State could be used for surveys, plans and engineering investigations of projects for future construction on the Federal-aid highway system of that State. Subsequent amendments have broadened the use of the 1-1/2 percent funds to include economic investigations and highway research necessary in connection therewith.

All States availed themselves of such funds and established highway planning survey departments as an important part of their organization. It was through the work of these departments that the Bureau of Public Roads could supply factual data to the Congress in response to the latter's directives to study and report on national highway matters.

Two outstanding reports aided in establishing the need for continuing the development of the nation's highways as was begun in 1916. The first, titled "Toll Roads and Free Roads," submitted in 1939, defined the location of three east-west and three north-south highways and concluded that financing of the full costs of such highways by direct-toll collections was not possible. However, this report contained what was in effect a master highway plan for the

entire nation. It recommended for consideration the modernization of the Federal-aid highway system and the construction of a special, tentatively defined system of direct interregional highways, with all necessary connections through and around cities, designed to meet the requirements of the national defense in time of war and the needs of a growing peacetime traffic of longer range. The second, titled "Interregional Highways," submitted in 1944, contained factual data of several integrated nationwide highway systems ranging from 14,200 to 78,800 miles in total extent. It was concluded that a system of 33,920 miles of principal highway routes which would reach to all sections of the country, plus an additional 5,000 miles of alternate and auxiliary routes at the larger cities, was the optimum which would afford the greatest possible service per mile.

These and other studies, such as "Highways for the National Defense," first submitted in 1941 and again in 1949, resulted in the inclusion in the Federal-Aid Highway Act of 1944 of the provision that "There shall be designated within the United States a National System of Interstate Highways not exceeding forty thousand miles in total extent so located as to connect by routes, as direct as practicable, the principal metropolitan areas, cities, and industrial areas, to serve the national defense, and to connect at suitable border points with routes of continental importance in the Dominion of Canada and the Republic of Mexico."

Between 1944 and 1947 the States and the Bureau cooperatively restudied the routes as proposed in the report "Interregional Highways." On August 2, 1947, the city-connecting routes of the Interstate System, estimated to be some 37,700 miles in length as computed from mileages along existing highways, were formally designated by the Federal Works Administrator. The 2,300 miles remaining from the 40,000-mile authorization were reserved for future designation as circumferential and distributing routes at the larger cities. These latter routes were designated in September 1955 by the Commissioner of Public Roads for the Secretary of Commerce.

The Congress in enacting the Federal-Aid Highway Acts of 1944, 1948, 1950, 1952, and 1954, gave recognition to the need for the modernization of the Federal-aid systems and authorized funds therefor in the amounts of from $450,000,000 to $700,000,000 per annum. Only token amounts were provided for the Interstate System, however, amounting to $50,000,000 under the 1952 Act, and $350,000,000 under the 1954 Act. Despite these sizeable sums, the finances were not sufficient to reduce or to eliminate the existing deficiencies in the highway facilities at a desirable rate. To secure more facts, the Congress in 1954 directed the Secretary of Commerce to make a comprehensive study of all phases of highway financing, including a study of the costs of completing the several systems of highways in the several States, and of the progress and feasibility of toll roads. In the same year, President Eisenhower appointed a President's Advisory Committee on a National Highway Program to conduct studies and to submit a report of its findings. The reports by the Secretary of Commerce, "Needs of the Highway Systems 1955-1984" and by the President's Advisory Committee, "A 10-year National Highway Program," were both submitted to Congress early in 1955. You will recall that these reports concluded that the cost to modernize all of the Nation's roads and streets would require an expenditure of $101 billion for construction, and that some $23 billion would be required for construction of the 37,700 miles (plus or minus) of the Interstate System routes that had been designated in 1947.

Congress gave extended consideration to these data as well as to other data presented in the many hearings held by the Public Works Committee of the Senate and the House of Representatives. The result was passage of the Federal-Aid Highway and the Highway Revenue Acts of 1956 approved by the President on June 29, 1956.

This legislation provides that revenues derived from Federal taxes between July 1, 1956, and June 30, 1972, on fuels used for highway purposes, on trucks, truck trailers and buses, on tread rubber, and on highway motor vehicles of gross weight of more than 26,000 pounds are to be set aside in a Highway Trust Fund in the Treasury of the United States. It has been estimated that the total receipts into the Highway Trust Fund during the 16-year period will be some $38.5 billion. Amounts in the Trust Fund are available by specific appropriation acts for making expenditures after June 30, 1956, to meet those obligations of the United States incurred under the Federal-Aid Highway Acts which are attributable to work performed on the Federal-aid highways. It is this Federal assistance in financing which makes it possible for the State highway departments to plan for and proceed at an accelerated rate on the modernization of the Federal-aid highway systems.

For the first time Congress has authorized a long-range program having the objective of completing an entire segment of the Federal-aid highway system—that segment being the 40,000-mile Interstate System authorized in 1944. Congress declared in the 1956 Act that one of the most important objectives is the prompt completion of the Interstate System, and that its early completion, along with accelerated construction on the other Federal-aid systems, is essential to the national interest. It is the declared intent of the Congress that the Interstate System be completed as nearly as practicable over a thirteen-year period and that the entire System in all States be brought to simultaneous completion.

To finance projects on the Interstate System, Congress has authorized a total of $25.0 billion of Federal funds in amounts varying from $1.025 to $2.2 billion per year for the fiscal years 1957 through 1969. This sum together with an estimated $2.645 billion of State matching funds totals $27.645 billion. This financing plan was in agreement with the cost as estimated in 1955 for the 37,700 miles (plus or minus) of System as designated in 1947, namely, $23.3 billion, plus an allowance of $4.0 billion for the 2,300 miles (plus or minus) of System as designated in late 1955, or a total of $27.3 billion for a 40,000-mile system.

The Federal-Aid Highway Act of 1956 provides for uniformity of rate of construction and the simultaneous completion of the entire System in all the States by the following procedures —

"All sums authorized . . . to be appropriated for the fiscal years 1960 through 1969, inclusive, shall be apportioned among the several States in the ratio which the estimated cost of completing the Interstate System in each State . . . bears to the sum of the estimated cost of completing the Interstate System in all of the States."

"As soon as the standards provided for . . . have been adopted, the Secretary of Commerce, in cooperation with the State highway departments, shall make a detailed estimate of the cost of completing the Interstate System as then designated, after taking into account all previous apportionments made. . . based upon such standards and in accordance with rules and regulations adopted by him and applied uniformly to all of the States."

"The Secretary . . . shall transmit such estimate to the Senate and House of Representatives within ten days subsequent to January 2, 1958."

"Upon approval of such estimate by the Congress by concurrent resolution, the Secretary . . . shall use such approved estimate in making apportionments for the fiscal years ending June 30, 1960, . . . 1961, and . . . 1962."

The same procedures are prescribed for subsequent estimates to be submitted to the Congress in January 1962, 1966, 1967 and 1968.

The first of the series of estimates has been made by the State highway departments and the Bureau of Public Roads. The 49 volumes of reports by the States and the District of Columbia, together with a "Report of Factors for use in Apportioning Funds for the National System of Interstate and Defense Highways applicable to the fiscal years 1960-1961-1962" were transmitted to the Congress on January 7, 1958, by the Secretary of Commerce. The "Report of Factors for Apportioning Funds" has been printed as House Document No. 300, 85th Congress, Second Session.

The State highway departments and the Bureau of Public Roads have thus accomplished the tasks assigned them by the Congress under the Federal-Aid Road Act of 1916 and all subsequent amendments. The latest report of January 1958 is now undergoing review by the General Accounting Office of the Federal Government at the request of the Subcommittee on Public Roads of the Senate Public Works Committee. It is expected that the review will be completed by or during April 1958 after which the Committees of Congress will resume hearings on the highway legislation that must be enacted to permit the Secretary of Commerce to apportion the Federal-aid highway funds for the 1960 and later fiscal years as authorized in 1956.

Now an explanation of the estimates of cost: what were the ground rules; what are the routes which were estimated; what are their mileages, and what is the meaning of the cost figures that are reported?

To establish uniformity in estimating procedures among the States an Instruction Manual was developed in cooperation with the State highway departments. After preliminary trial and explanation this manual was issued to all participants in October 1956. Basic ground rules are —

The System to be estimated was restricted to those routes approved as to function and in general location on August 2, 1947, and September 15, 1955, having an estimated length of not more than 40,000 miles.

The States and the Bureau were to reach agreement as to the location of the cited routes which would serve as basis of estimate of work to be done, and to determine which toll roads and other toll facilities such as bridges and tubes were to be designated as parts of the System.

A base level of condition or stage of development of each route from which an estimate of additional work could be computed was established as the level of development achieved when the work in authorized status as of July 1, 1956, shall have been accomplished.

Completing the Interstate System was defined to mean bringing the routes of the 40,000-mile System from their base level of development as defined above to the status of an integrated net of controlled access highways on the locations approved for these routes, with all sections adequate to accommodate the types and volumes of traffic forecast for the year 1975 and in reasonable conformity with the geometric and construction standards approved on July 17, 1956 for projects on that System.

Traffic forecasts were to be made in accordance with practices followed by the States, subject to check by procedures issued by the Bureau of Public Roads.

The standards for the System are those adopted by the American Association of State Highway Officials and approved by the Commissioner of Public Roads.

The costs were based on prices prevailing in the last half of 1956 for work of similar nature in each State.

Locations on which work was estimated were shown on strip maps with symbols to indicate correlation with other roads and streets and the structures deemed necessary. Each route was broken down into sections which were identified by letter symbols on the strip maps.

Design classification data were established for each section of each route. Typical cross sections showing the geometrics of the designs for which costs were estimated were to be provided.

Quantities of work were to be estimated for each section in accordance with the design classification data. Work sheets were retained in files of the States, but estimated costs were reported for some 15 items of work for each section of each route.

Code entries on the submitted tables permitted identification of the type of highway, whether in rural or urban area, whether a toll or free section, the proposed method of financing, and similar data.

General guides outlined a number of features of freeway construction not specifically included under the approved standards that might be included in the estimated work and cost report.

All field estimating work was to be accomplished so that the States' reports would be available to the Bureau of Public Roads at Washington by July 1957.

The city-connecting Interstate System routes that were estimated are shown in general location on the small map, Plate A. The length of these routes, plus lengths of the auxiliary routes at the larger cities, as was estimated on their actual or proposed construction locations, and shown in each State's report, is 38,548 miles.

Included in this 38,548 figure are some 2,142 miles of toll roads, bridges, and tubes. The toll-free sections of the Interstate System thus total about 36,406 miles. All or a portion of the toll highways in the States of Connecticut, Florida, Illinois, Indiana, Kansas, Kentucky, Maine, Maryland, Massachusetts, New Hampshire, New Jersey, New York, Ohio, Oklahoma, Pennsylvania, Texas and Virginia have been designated as parts of the Interstate System.

The total estimated cost for preliminary engineering, rights-of-way and physical construction for the 38,548 miles of free and toll portions of the Interstate System is $39,510,787,000. Administrative, research and related costs are not included in this figure nor have they been estimated.

The total estimated cost for work expected to be financed with other than Federal-aid Interstate and State matching funds is reported to be $1,940,474,000.

The total of Federal-aid apportionments made under the 1956 Act for the 1957-1958-1959 fiscal years plus State matching funds, and of the balances as of July 1, 1956, of previous apportionments made under the 1952 and 1954 Acts plus State matching funds, was calculated by the Bureau to be $5,428,258,000. This amount is available to finance a portion of the work estimated to be done after July 1, 1956, but not in authorized status as of that date.

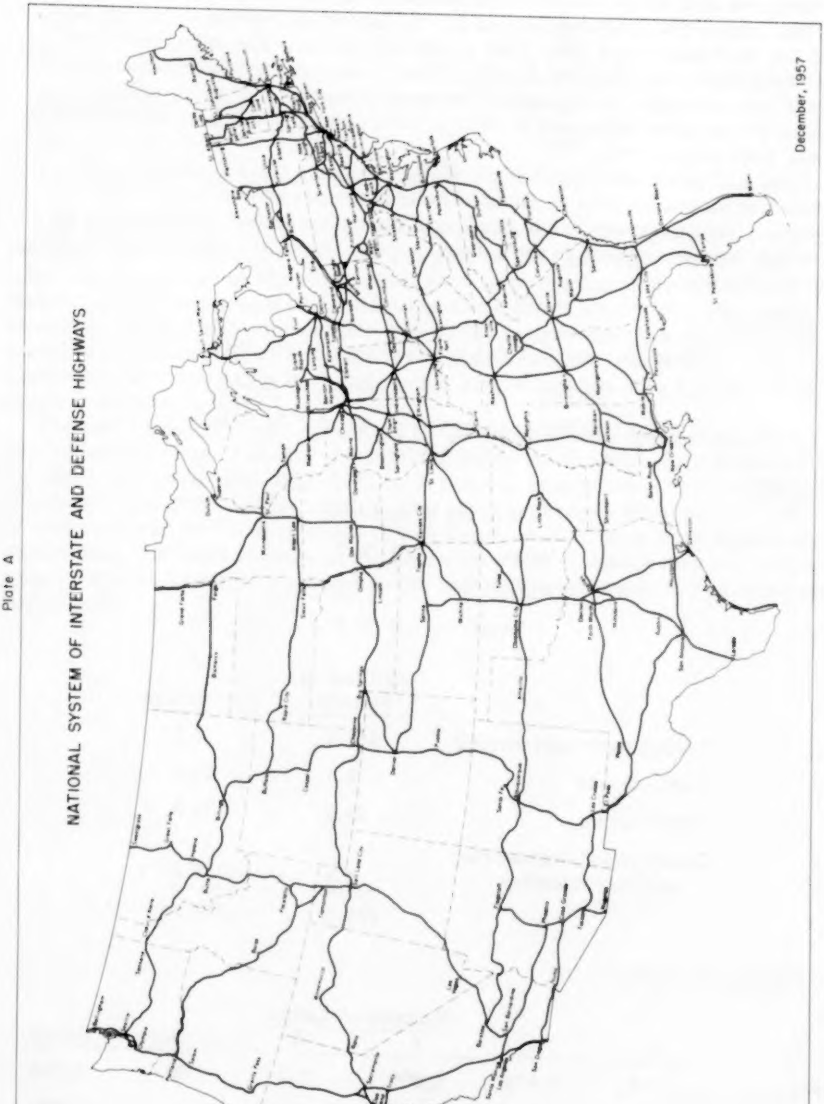
Plate A
NATIONAL SYSTEM OF INTERSTATE AND DEFENSE HIGHWAYS
December, 1957

The net remaining estimated cost for completing the Interstate System to be borne by Federal-aid Interstate funds authorized for the 1960-1969 fiscal years plus State matching funds is $39.5 billion less $7.4 billion or $32.1 billion, and this is the cost to complete the 36,406 miles of free highways.

The sum of the funds authorized for the Interstate System under the 1956 Act for the fiscal years 1960-1969 is $20.125 billion. The estimated State matching funds required are $2.075 billion. Thus, some $22.2 billion are tentatively available in comparison to an indicated need of $32.1 billion should the work as estimated in 1957 at 1956 prices be actually accomplished at the 1956 price level.

After analyzing and checking the 49 State reports the Bureau of Public Roads has placed all data on computer cards for preparation of statistical reports. These reports are in readiness for consideration by Congress but have not been distributed to the general public. However, some of these data are as follows:

Mileage:

Urban	4,568	Free	36,406
Rural	33,980	Toll	2,142
Total	38,548	Total	38,548

Costs:

	(Billions of dollars)
Urban	$ 22.3
Rural	17.2
Total	$ 39.5

	Billions of dollars	Percentage
Preliminary engineering	$ 1.4	3.5
Right-of-way	5.3	13.5
Construction	29.9	75.6
Construction engineering and contingencies	2.9	7.4
	$39.5	100.0

Mileage by lanes:

	Number of Lanes					
	2	4	6	8	10 or more	Totals
Urban	12	1,978	1,695	817	66	4,568
Rural	1,844	30,195	1,556	385	None	33,980
Total	1,856	32,173	3,251	1,202	66	38,548
Percent	4.8	83.5	8.4	3.1	0.2	100.0

Number of Structures - Rural Areas Only	
Bridges over 1,000 feet total length	220
Bridges less than 1,000 feet total length	6,765
Interchanges	8,763
Highway Separations	9,546
Railroad Separations	1,452
Highway-railroad Separations	405
Tunnels more than 500 feet total length	20

The State highway departments and the Bureau of Public Roads have in fact submitted an engineering consultant's report to the Congress. More than 1,200,000 man hours of effort are estimated as having been devoted to this report. It has been prepared in much the same detail as are reconnaissance reports for budget and construction scheduling operations. The work as estimated is in accordance with the approved standards, and where standards higher than the minimums have been used, they are not of a range that would result in excessive cost.

The estimates have been submitted to Congress with recommendation that they be approved as basis for apportioning funds for the Interstate System for the three years 1960-1961-1962 such that the rate of construction of the System in each State will be uniform. No one can foretell what the decision of Congress will be but it is hoped it will decide soon to accept its consultant's report such that work already in the advanced stage of design may proceed to construction in an orderly manner to the extent that presently levied revenues will permit.

Paper 1805 October, 1958 HW 3

Journal of the
HIGHWAY DIVISION
Proceedings of the American Society of Civil Engineers

THE FEDERAL AID HIGHWAY PROGRAM IN NEW YORK STATE[a]

John W. Johnson,[1] M. ASCE
(Proc. Paper 1805)

ABSTRACT

This paper refers briefly to the continuing cooperated action of the Federal and State Governments in the building of the Nation's highways from 1916 to the present day. A synopsis is developed of New York State's multi-billion dollar construction program with illustrative comments on area alignments. It concludes with the report on the State's program to enlarge its engineering staff to meet the increased work load.

Contrary to popular notion, the Federal Government did not always contribute funds for highway construction. In fact, for many years its only concern was with management, methods of construction and other investigations relative to highways. It financed only the collection and distribution of the information obtained. It was not until 1916 that the Congress enacted the Federal Aid Road Act. This provided the foundation upon which the cooperative action of the Federal-State highway program has continued in existence until the present time. One of the important requirements of this first Act was, that each State was to have a highway department capable of administering the funds provided. Up to that time many States were not so organized, and highway planning and construction floundered accordingly. The original concept of the Act, which still continues today, apportions Federal grants to the States according to a formula in which weight is given to relative area, population, and rural mail-route mileage.

These Federal grants for highway construction must be matched by the States in varying proportions with their own money.

Note: Discussion open until March 1, 1959. To extend the closing date one month, a written request must be filed with the Executive Secretary, ASCE. Paper 1805 is part of the copyrighted Journal of the Highway Division, Proceedings of the American Society of Civil Engineers, Vol. 84, No. HW 3, October, 1958.

a. Presented at the June, 1957, ASCE Convention in Buffalo, N. Y.

1. Superintendent of Public Works, State of New York.

All States have retained the initiative and the prerogative to propose roads to be improved and the type of improvement, and are responsible for surveys, plans and specifications, right-of-way acquisition, letting of contracts and supervision of construction, subject to the approval of the Federal Bureau of Public Roads.

Legislation through the years has provided increasing amounts of money and has been extended to include other types of roads and streets. The Federal Aid Highway Act of 1944, for the first time, authorized specific Federal funds for use in urban areas. The act that year also called for the designation by the States and the Bureau of Public Roads of a National System of Interstate Highways.

In the Federal Aid Highway Act of 1956, the means has been provided for the States to undertake the greatest public works program in the history of the country. One of the most important provisions of this Act was the assurance of an accelerated completion of the Interstate System. This system is made up of the main highway routes of the nation which link together 90 percent of the cities having populations of 50,000 or more together with many similar cities and towns. This system, now numbering 41,000 miles, is located approximately as shown in Figure I. When measured in distance, the network has only about 1.2 per cent of the Nation's total road and street mileage, but when completed it will carry 20 percent of all the traffic. It will be of invaluable benefit to long distance travel with its design for control of access, without crossings at grade and the limitations of grade and curvature. It will serve equally well the short range travel along its lines by providing connections to handle suburban and urban traffic through areas of congestion.

During the initial period, 1957-1959, New York State will receive approximately $507 million of Federal highway aid, according to the existing formula, of which $345 million is assigned to construction of its Interstate Highways which, at this writing, total 1235 miles. Thereafter funds will be disbursed according to basis of need to complete the system.

Since the Federal Bureau of Public Roads regards the 577-mile New York State Thruway as included in this allotment, represented by the unbroken black line on Figure II, the Mileage in the State eligible for 90 percent funds is actually cut in half. This has placed us in the peculiar position of being penalized for having constructed so large a portion of our Interstate System without Federal help.

During the time that the present Federal Aid Bill was in the making New York, along with some other States similarly affected, fought hard to have a specific reimbursement clause spelled out in the Bill. This, however, was only partly successful as Congress authorized merely a study of the whole reimbursement problem. We are hopeful that this study will establish the justice of our claim.

While we are pressing forward in the construction of our Interstate System, we are none the less cognizant of the importance of the other State highways on the primary, urban and secondary systems which constitute the feeder routes to these major expressways. Figure III shows the main travel corridors within the State in some of the urban and rural areas. While most of these highways rival the Interstate routes in traffic volumes and importance to industrial development, they must be reconstructed from funds based upon the old formula of 50 percent State matching 50 percent Federal funds. Federal aid for these types of highways has been increased slightly under the new Bill.

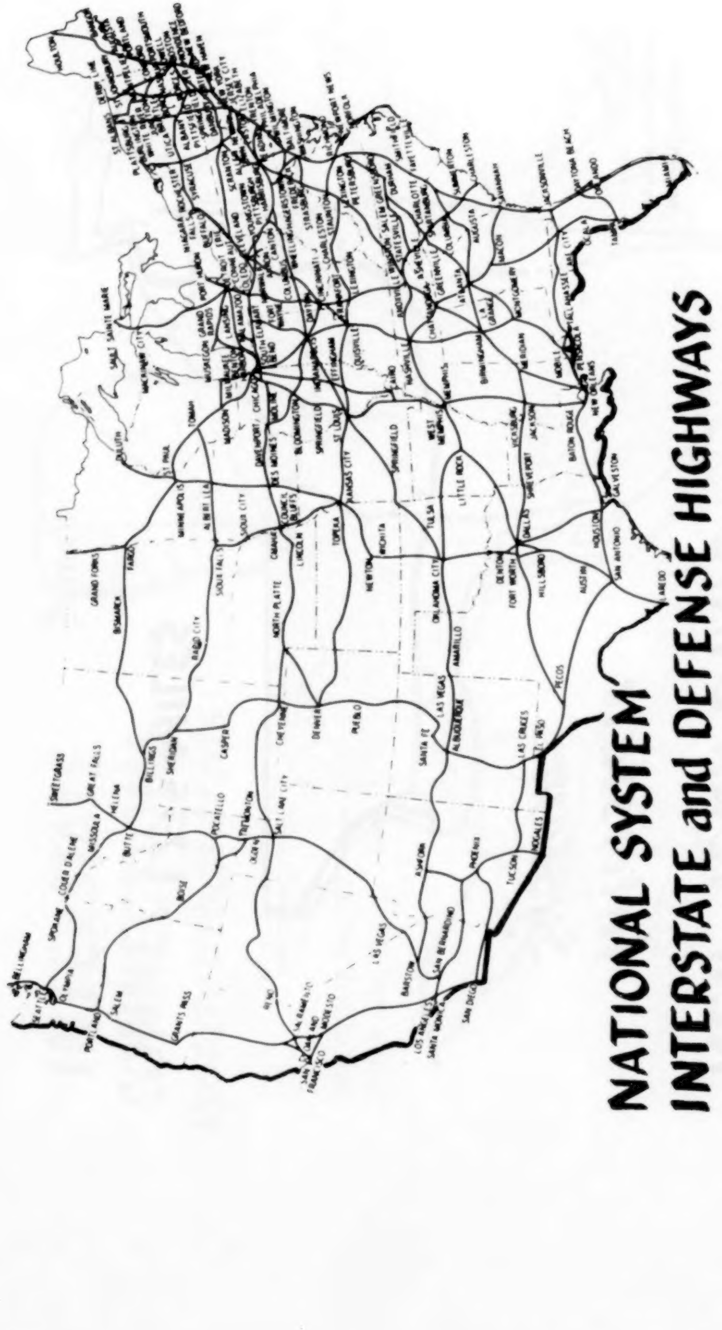
NATIONAL SYSTEM
INTERSTATE and DEFENSE HIGHWAYS
SEATTLE
PORTLAND
SALEM
SPOKANE
BOISE
BUTTE
MISSOULA
HELENA
GREAT FALLS
SWEETGRASS
BILLINGS
SHERIDAN
CASPER
CHEYENNE
DENVER
PUEBLO
SALT LAKE CITY
OGDEN
POCATELLO
RENO
SACRAMENTO
SAN FRANCISCO
LOS ANGELES
SAN BERNARDINO
SAN DIEGO
BARSTOW
LAS VEGAS
PHOENIX
TUCSON
NOGALES
SANTA FE
ALBUQUERQUE
LAS CRUCES
EL PASO
PECOS
AMARILLO
OKLAHOMA CITY
FORT WORTH
DALLAS
AUSTIN
SAN ANTONIO
LAREDO
HOUSTON
GALVESTON
TULSA
WICHITA
NEWTON
TOPEKA
KANSAS CITY
LINCOLN
NORTH PLATTE
SIOUX FALLS
SIOUX CITY
FARGO
BISMARCK
GRAND FORKS
MINNEAPOLIS
ST PAUL
DULUTH
MADISON
CHICAGO
ST LOUIS
SPRINGFIELD
LITTLE ROCK
MEMPHIS
JACKSON
VICKSBURG
SHREVEPORT
BATON ROUGE
NEW ORLEANS
MOBILE
BIRMINGHAM
NASHVILLE
LOUISVILLE
INDIANAPOLIS
ATLANTA
MONTGOMERY
MACON
AUGUSTA
SAVANNAH
JACKSONVILLE
DAYTONA BEACH
TAMPA
CHARLESTON
CHARLOTTE
RICHMOND
PITTSBURGH
CLEVELAND
DETROIT
TOLEDO
BUFFALO
SYRACUSE
ALBANY
SAULT SAINTE MARIE
MACKINAW CITY

FIGURE I.

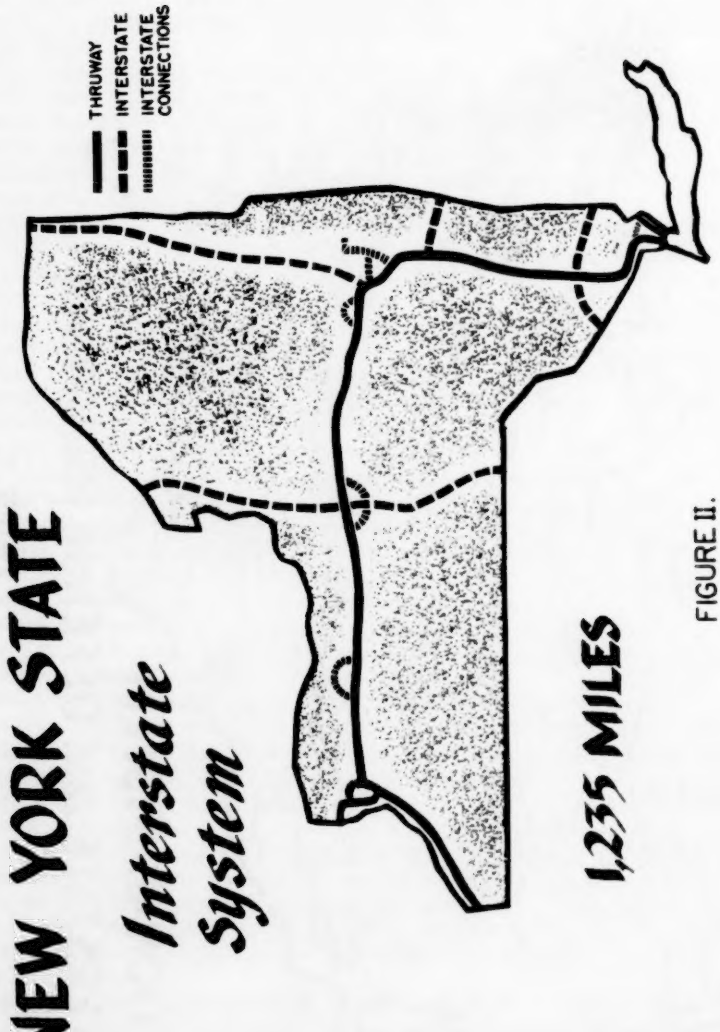
NEW YORK STATE
Interstate System
THRUWAY
INTERSTATE
INTERSTATE CONNECTIONS
1,235 MILES

FIGURE II.

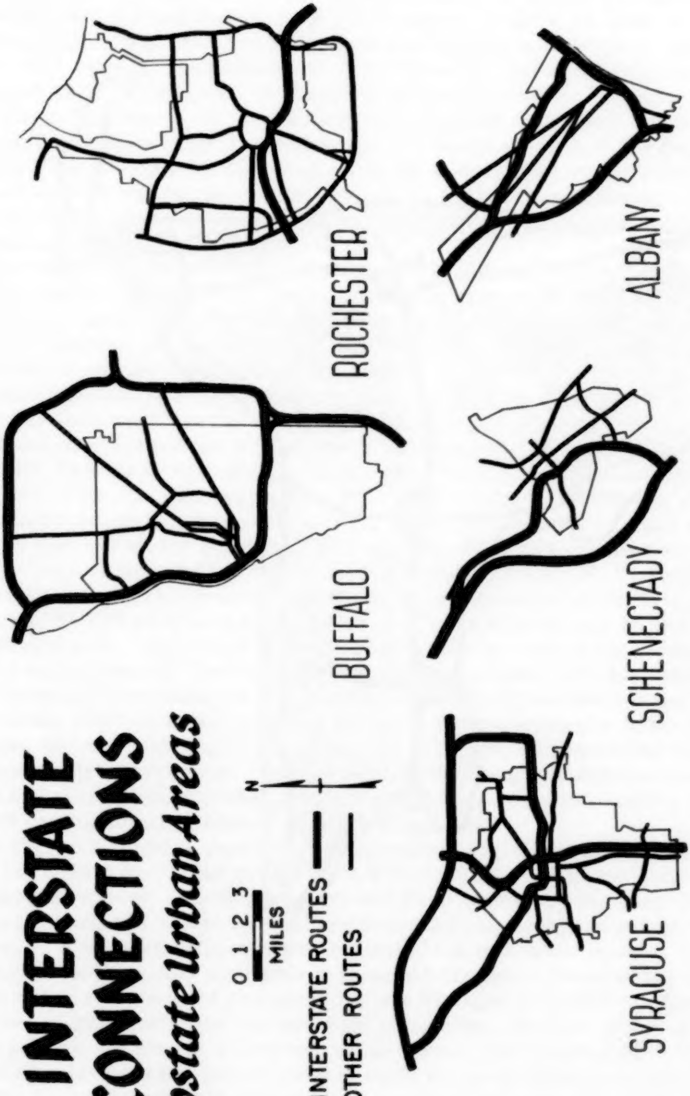
INTERSTATE CONNECTIONS
Upstate Urban Areas
0 1 2 3
MILES
N
INTERSTATE ROUTES
OTHER ROUTES
SYRACUSE
SCHENECTADY
ALBANY
BUFFALO
ROCHESTER

FIGURE II-A

MAIN TRAVEL CORRIDORS

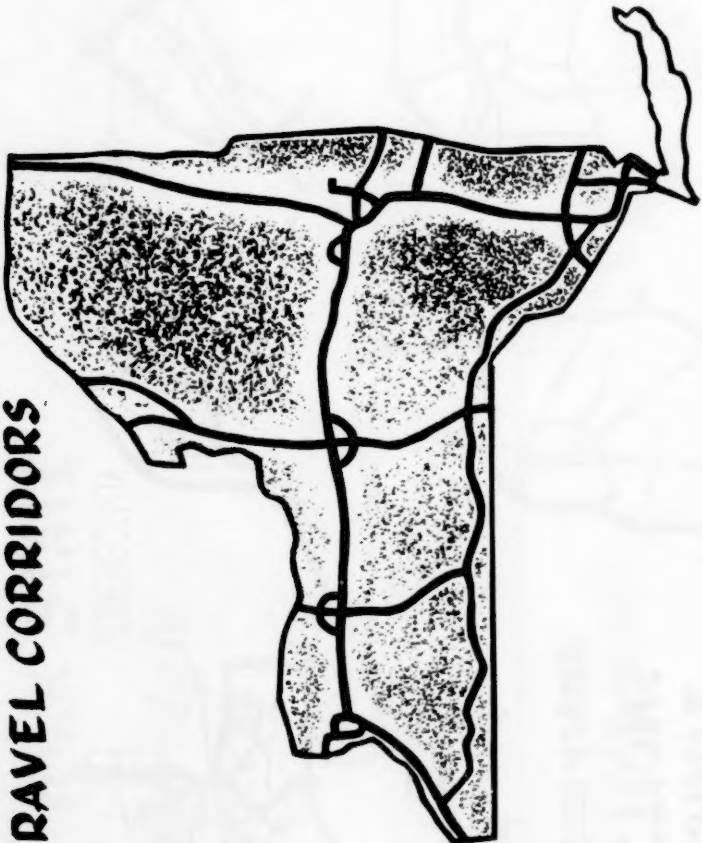

FIGURE III.

According to the report of the Temporary Highway Finance Commission, New York State's costs for a twelve-year minimum program will amount to \$2,187,000,000 at today's prices. A great amount of the work, such as parkways and railroad grade eliminations, will be paid with 100 percent State funds. The balance, augmented with Federal Aid of \$2,350,000,000, puts the total cost at \$4,537,000,000. Fortunately, we find ourselves well able to absorb all of this money. In fact, we could use a great deal more, especially in the area of urban arterial construction. At the present time the Department of Public Works has obligated all of the Federal Aid money which will become eligible for reimbursement on July 1, 1957. Then following the July 18, 1957 letting we will have obligated all but \$50 million of our first two years' allocation of Interstate monies.

This has been achieved through great effort on the part of our engineering staff as well as our increased use of consulting engineers, so that the Federal Aid Highway Act of 1956 has found us with a design program well under way. The program has now grown to the point where \$1,121,000,000 worth of projects are now in various stages of design.

These are fantastic figures and the question is often proposed why such sums are necessary. In figure IV are shown the mileage of the various types of highways, roads and streets in New York State, which total 104,000 miles. While the Federal Government participates in the construction and reconstruction of the State highways, New York through State Aid, in turn, participates in the construction of county, town, city and village streets and roads.

This then raises the question, "Why must we build new expressways—why not reconstruct the existing highways of this great mileage?" To this there are several answers. Around 1870 the relative population of the City of New York was 64,000 persons per square mile. Today that ratio is 15,000 persons per square mile. And where have the people gone in light of the tremendous growth in population? To the suburban and rural areas; with the result that area occupancy continues to change with population moves from urban regions. With urban concentration remaining static or being continually reduced, the existing highway facilities, even when reconstructed, will no longer adequately support the traffic volumes. People are now traveling greater distances for work and recreation, with the resultant demand that time in reaching their required destinations be reduced as much as possible.

In Figure V we have shown the actual vehicle registrations increase in New York State during the period from 1920 to 1956. Estimates indicate that the present number of motor vehicles will have doubled by the year 1975. All of the planning and design for the Interstate System, by agreement of all States, is based on traffic volumes estimated for this latter year.

New York State also possesses a blueprint for action in the urban arterial plans which we have been preparing for our 62 cities since 1944. However, because of inadequate construction fund allocations, we have fallen behind each year in our efforts to improve urban travel. By the year 1955, the legislative process had placed most of these urban arterial programs on the Statute Books to create an obligation to construct these routes at an estimated cost of \$2-1/2 billion. With such a backlog of projects, it is readily understood why we shall have no difficulty in absorbing all State and Federal funds made available for these arterials over the next several years.

Figure VI outlines the intricate treatment proposed for the metropolitan area of New York City. Great costs are involved here in carrying out this work because many structures must be built to carry highways over streams,

MILEAGE by HIGHWAY SYSTEMS

	RURAL	URBAN	TOTAL
INTERSTATE SYSTEMS	819	416	1,235
PRIMARY SYSTEM	7,933	1,316	9,249
SECONDARY SYSTEM	3,711	290	4,001
COUNTY ROADS	17,608	1,235	18,843
CITY STREETS	——	15,662	15,662
TOWN ROADS	55,010	——	55,010
	85,081	18,919	104,000

FIGURE IV.

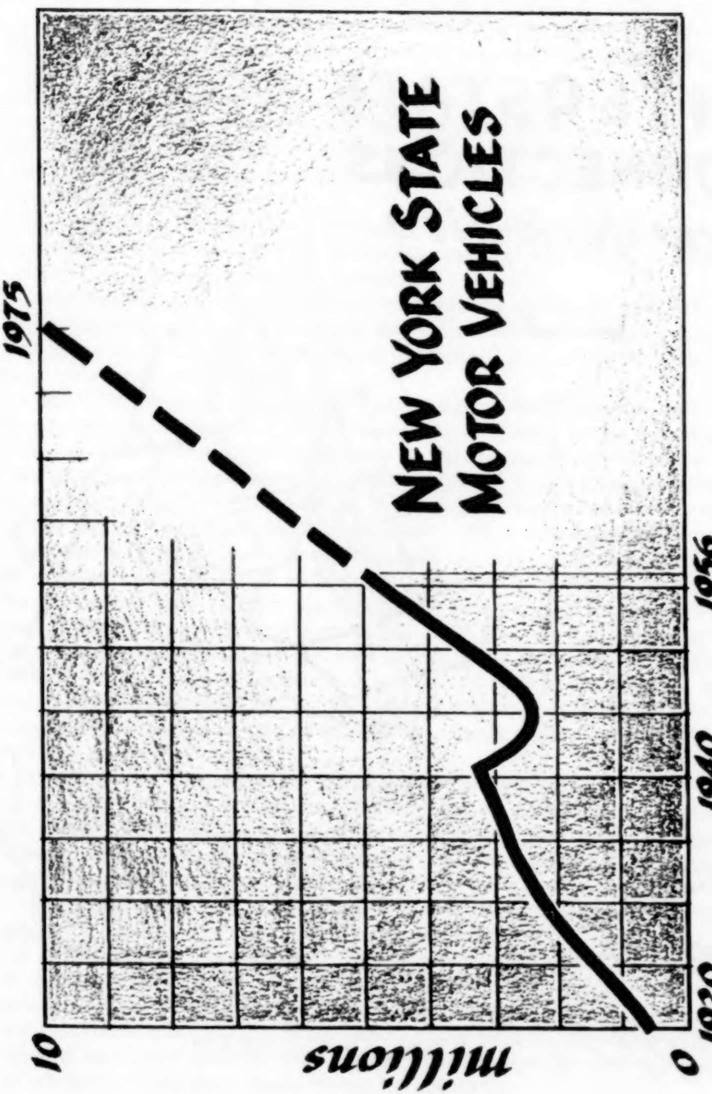
NEW YORK STATE
MOTOR VEHICLES
millions
10
0
1920
1940
1956
1975

FIGURE V.

INTERSTATE CONNECTIONS
New York City

FIGURE VI.

commercial areas and other highways. To illustrate modern-day highway construction costs through urban areas, we have recently awarded a contract for a one-mile section of the Brooklyn-Queens Expressway at a bid price of $15,547,121.60. This, let me add, does not include the cost of acquiring a most expensive right of way.

Development of the plan for the urban areas in Western New York, which includes the Tonawandas, the cities of Buffalo and Lackawanna, is shown in Figure VII. Here also the arterial and Interstate routes are to be constructed to provide satisfactory facilities for complete and free circulation of traffic in and out of the congested areas.

In Figure VIII is the planned development of the Capital District area involving several urban centers, all being integrated to allow direct, safe and high speed travel between these communities.

The willingness on the part of New York State to match all Federal funds and, in addition, to allocate increasing amounts to projects which require 100 percent State participation has contributed much to our ability to keep abreast of our construction schedules.

Perhaps our greatest difficulty in maintaining such a program, and one with which all other State Highway Departments are familiar, is the securing of sufficient numbers of qualified engineers to handle the work. We have been plagued by our inability to continually match the ever spiralling salaries which engineers now command. Most engineering students receive unusually attractive offers long before their graduation. We are attempting to cope with this situation by improved contacts and offers in early recruitment and by a broad training program which we hope will eventually provide us with a sufficient engineering staff. Under the training program, we give our personnel who are not yet engineers an opportunity to enlarge their knowledge by college courses-and the scope of their activities by widened experience. In this way we seek to build a force of technicians capable of relieving engineers of many routine steps in their daily work. The more ambitious of these technicians can continue their studies, and eventually take their places as accredited engineers.

It is well known that budgetary officials are usually skeptical toward requests for increasing expenditures. Fortunately we have convinced our Budget people of our great deficiencies in personnel for undertaking the expanding work load. With their active assistance, we have worked out a far-reaching reorganization of our present department. By regrouping our bureaus and functions, it is hoped that we can achieve better coordination and relieve key personnel of much of the routine and time-consuming work.

The nationwide highway construction program inaugurated last year represents one of the greatest challenges in our Nation's history. As highway engineers it will be our job to see that it is carried forward with integrity of purpose and with a dedication to the needs of the people. I feel confident that by working and consulting together we can find the strength and the will to accomplish these stupendous tasks which lie before us.

INTERSTATE & ARTERIAL ROUTES
Buffalo & vicinity

FIGURE VII.

INTERSTATE & ARTERIAL ROUTES
Capital District Area

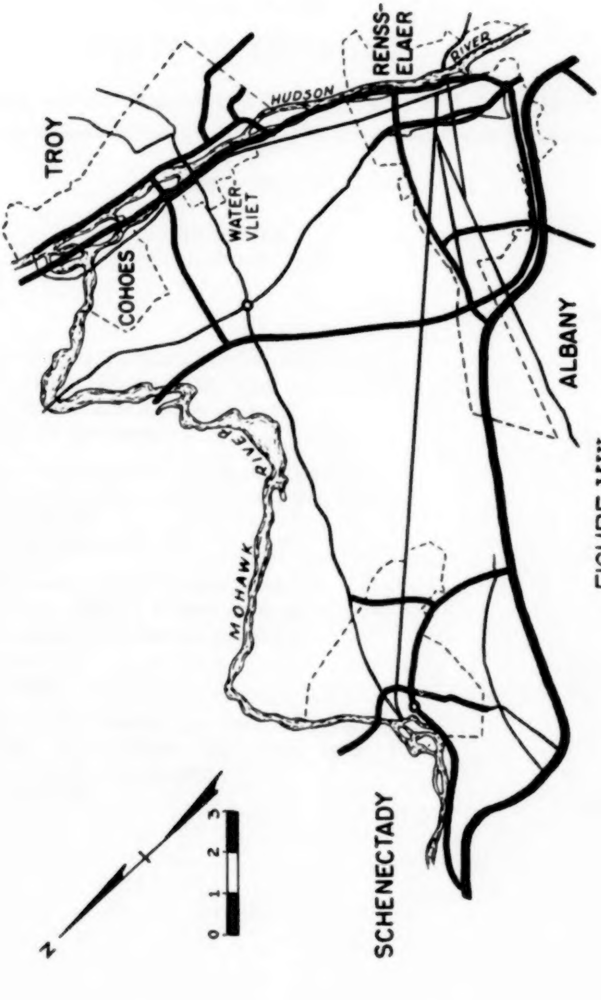

FIGURE VIII.

Journal of the
HIGHWAY DIVISION
Proceedings of the American Society of Civil Engineers

CONTENTS

DISCUSSION
(Proc. Paper 1829)

Note: Paper 1829 is part of the copyrighted Journal of the Highway Division, Proceedings of the American Society of Civil Engineers, Vol. 84, HW 3, October, 1958.

DIRECT SOLUTION FOR TRIPLE SPIRALED COMPOUND CURVE[a]

Closure by Alfred C. Scheer

ALFRED C. SCHEER,[1] J. M. ASCE.—Professor Hickerson's pertinent discussion adds to the value of the paper and raises some points worthy of further comment.

Throughout the paper, the subscript 1 is reserved for the flatter curve, and the subscript 2 for the sharper curve. The choice of subscript is therefore independent of the direction of the stationing, and there is no necessity to interchange subscripts just because the stationing happens to proceed from the sharper to the flatter curve. In the second paragraph of the discussion, Professor Hickerson had already interchanged subscripts once, because he was assuming that the subscript 1 would be used for the sharper curve.

If the recommended subscript convention is observed, the algebraic sign of all three offsets will always be positive, and there is therefore no need to adopt a formal sign convention for the offsets. If, however, the subscript 1 is used for the sharp curve, it is then true, as Professor Hickerson points out, that the algebraic sign of 0 should be considered negative.

Professor Hickerson has demonstrated the versatility of the method by writing expressions for F_1 and F_2 for a three-centered compound curve. (The = sign on Line 9 of Page 1526-8 is a printer's error, and should be replaced by a minus sign). When using these equations, however, a formal sign convention for the offsets, as explained below, is needed.

For a three-centered compound curve, one may start at either end and use the subscripts 1, 2, 3, and 4 for the offsets, in the order that they are encountered. When this is done, an offset will be considered positive when it represents an <u>inward</u> shift, negative when it represents an <u>outward</u> shift. For instance 0_1 will always be positive because it represents an inward shift of the first curve. If the second circular curve is flatter than the first one, then 0_2 will be negative, because it will represent an outward shift of the second curve. If the third curve is sharper than the second, then 0_3 will be positive, because it will represent an inward shift of the third curve. 0_4 will always be positive, because the net resultant shift of the last curve, from the final tangent, will always be inward.

For ease of calculation, Professor Hickerson's formulas (c) and (d) are certainly advantageous. From the teacher's viewpoint, however, there is a distinct advantage in keeping T and F separated, because the student is more likely to exercise his mind, and visualize the geometry of the problem, if he is required to calculate T and F independently.

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a. Proc. Paper 1372, September, 1957, by Alfred C. Scheer.

1. Associate Prof. of Civ. Eng., Montana State College, Bozeman, Mont. Formerly Associate Prof. of Civ. Eng., South Dakota School of Mines & Technology, Rapid City, S. Dak.

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OPERATION OF URBAN EXPRESSWAYS[a]

Closure by Joseph Barnett

JOSEPH BARNETT.[1]—It is almost inevitable that an attempt at an engineering analysis, in this case the cause and suggestion for cure of breakdowns of freeways due to overload, invites discussions that are not pertinent to the analysis. This is not undesirable for it often brings to the fore ideas which are worthwhile and, therefore, are appreciated.

Mr. DeLeuw's discussion agrees with that part of the paper dealing with the causes of breakdowns and offers mass transit as a necessary solution to bring freeway volume within reach of capacity. The need for mass transit in our larger cities has long been recognized and the problems, particularly financing, are worthy of the thinking of our greatest engineering minds.

Mr. Moskowitz' discussion is interesting and provocative. There appears to be an important difference of concept with respect to the causes of breakdowns as described in the article and illustrated in Fig. 1. Delay through stop and go operation of course does not cause breakdown or result in zero capacity. As Mr. Moskowitz points out measuring volume to indicate capacity must be done over an appreciable period of time. When, however, stoppage is not voluntary or controlled, as is the case where caused by overload, and lasts many minutes, several times those many minutes are required to unravel traffic so that it again operates reasonably well. For these conditions the term "breakdown" is not inapplicable regardless of the total volume carried over several hours. The public for whom these freeways are built and whose vast sums are expended are not satisfied with such operation.

Perhaps the difference in concept can best be described using the very illustration Mr. Moskowitz uses, namely Fig. 1 in the article and then his Fig. B in which he attempts to show how nicely traffic picks up again after an assumed 16 minute delay by the stopped car of Fig. 1. He states that the "two open lanes carried traffic at a rate of 3,200 vehicles per hour . . ." during the time the car of Fig. 1 is stopped. This is just the point. When all lanes are moving near possible capacity, an <u>involuntary</u> stop as assumed in Fig. 1 is followed by maneuvering of drivers to get around the stopped car which soon results in all lanes slowing down and stoppage of all lanes often follows. This has been observed frequently on eastern freeways. It is fortunate indeed when, under such circumstances, traffic on the free lanes continues to move at a rate of a few hundred vehicles per lane per hour. Improved operation generally requires police officers to control traffic as by stop and go as described by Mr. Moskowitz. If, on the other hand, volume can be kept well

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a. Proc. Paper 1374, September, 1957, by Joseph Barnett.

1. Deputy Asst. Commr., Bureau of Public Roads, Dept. of Commerce, Washington, D. C.

below possible capacity before the involuntary stop is made, there is some leeway for such maneuvering and some slowing down does not reduce the capacity of the open lanes.

It is not intended, as Mr. Moskowitz implies, that only ramps near the area of congestion be controlled thus favoring long-haul traffic at the expense of short-haul. Such ramps have been closed on freeways in New York and in Texas, not for the purpose suggested in the article but because the interference at the particular ramp entrances forced such closures. As a matter of fact most freeways being designed and constructed now have too many interchanges and it is inevitable that some ramps will be closed in later years as traffic approaches capacity. What the author proposed is a study of a long freeway and that ramps in all areas be controlled to insure a peak hour volume at the most critical section a little less than possible capacity.

The writer is disappointed that the paper brought forth no attempt by traffic engineers to further explore the suggested procedure for controls and no offer of trial on an existing freeway on which the described breakdowns occur regularly. Without the further development of the suggested procedure and a field trial, it will always remain a moot question whether it would work. Admittedly it would take administrative courage of a high order. In the meantime, we will have to live with the hit-and-miss procedure of drivers seeking alternate routes following each freeway breakdown. In the long run, however, we are bound to meet the problem of efficient operation of costly urban freeways by planned control of traffic at entrance ramps.

QUALITY CONTROL FOR LARGE HIGHWAY PROJECTS[a]

Discussions by Wilson L. Davis and Lewis H. Tuthill

WILSON L. DAVIS,[1] A. M. ASCE.—Mr. Abdun-Nur is to be congratulated for a well prepared paper on an important and interesting subject.

In the paper there are several statements on which this writer would like to comment.

This writer heartily agrees with the selection of the quality desired and the providing of specifications that assure the attainment of that quality rather than determination of a quality as a result of a price which someone thinks should be paid. The procedure of selecting quality as the result of price has been one of the major factors in many pavement failures.

There is one additional requirement or stipulation that should be considered in connection with allowing increased thickness of layers of granular materials in earthwork even when the contractor attains the required density. The contractor should be required to attain the specified density, or more, in all parts of the layer. If a thick layer is used and the average density of the layer just meets the minimum density requirements the lower portion of the layer may have a density that is considerably below the minimum. If numerous layers are placed in this manner the resulting fill may settle excessively because the high density of the material in the upper part of the layer will not prevent the low density material from consolidating.

The author has stressed the need for training in the development of an inspection force and states:

> "It is advantageous at times to open training meetings to contractors, superintendents and foremen, so that they become familiar with what is expected of them and how it is to be met."

Similar meetings have been held on a number of U. S. Army Corps of Engineers projects where motion pictures have been shown to the inspection force and at the same time to selected contractor personnel such as superintendents, foremen, etc. These movies cover the construction of the type of pavement that will be built on that particular project. There are two films covering rigid pavement construction and three covering flexible pavement construction. These movies give broad general coverage of the duties of the inspector in the field and in the project laboratory and a general step by step coverage of airfield pavement construction. The showing of these movies and the resultant discussion that takes place at these meetings has been helpful.

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a. Proc. Paper 1626, May, 1958, by Edward A. Abdun-Nur.

1. Engr., Chf., Soils and Materials Branch, North Central Division, Corps of Engrs., U. S. Army, Chicago, Ill.

LEWIS H. TUTHILL.[1]—In this timely paper, Mr. Abdun-Nur has reminded us, as we sometimes need reminding, that inspection is a vital part of engineering for construction and that it can be rewarding beyond the general value of an insurance premium.

When a project or agency develops and trains a competent engineering inspection force, it is soon recognized by contractors, that fair, businesslike, competent inspection and control soon puts their operations on a consistent basis of uniformly high production with quality, that is not costly to them and in many cases actually increases their profits. For this reason such organizations are soon favored with good bid prices by experienced contractors and above-average workmanship is secured without added cost.

Considering the high standard of construction obtained, material costs are minimum with good inspection because materials are used with the greatest efficiency. For instance, when cement is paid for as a separate item, less can be used when concrete production is controlled to give good uniformity than when an extra increment of cement, together with sand and water, must be used as a margin of safety against unfavorable variations in workability and strength.

We must recognize, however, that such first class engineering inspection and its beneficial results cannot be obtained without, first, an unquestionably clearly-evidenced policy in its support being enunciated and unreservedly upheld by top management; and second, specifications such as those Mr. Abdun-Nur has described which spell out clearly and fully what is to be done.

Specifications sometimes lack vital clarity and completeness through adhering too closely to the idea that they should state only what is wanted, not how it shall be done. Obviously, this idyllic limitation is much to be desired if it were practical. However, the hard facts of reality are such that specifications written by a staff bemused by this ideal are often lacking in requirements and controls that long experience has shown are necessary if desired results are to be obtained. These are necessary because, first, it is not always possible to measure and confirm that what is wanted is provided step-by-step as the work is performed; and second and mainly, when it is possible, and results are not up to standard, it is too often inexpedient to change methods or equipment sufficiently at that late date as necessary to insure proper performance consistently.

CORRELATION OF GEOMETRIC DESIGN AND DIRECTIONAL SIGNING[a]

Discussion by Stephen G. Petersen

STEPHEN G. PETERSEN,[1] M. ASCE.—The points which Mr. Webb makes for considering the signing as an integral part of the overall design of a new freeway facility are well made. The extensive experience which he has gained from working with the Freeway System in California and relates in this paper should be an excellent guide. Has Mr. Webb or anyone else ever conducted any experiments to determine its effect?

In a very limited study of an exit ramp on a local freeway type facility, the writer found that as motorists neared the nose or "gore", there was a distinct tendency to "dive" for the ramp from the center and left lanes of this three-lane (one-way) facility with complete disregard for the size of the gap through which they had to pass in right lane traffic. This was so in spite of the fact that there was plenty of advance signing and a completely adequate deceleration lane. The closer this maneuver was made to the "gore", the smaller the gap accepted and, in many instances, the more hazardous the maneuver became. From observation, it appeared that the motorist who would make this maneuver would wait until they saw the overhead sign at the "gore" then dive for the exit without regard for the "other guy".

From these limited observations, the question arises as to whether there should be a sign at the "gore" which would give this last minute information to the motorist. Might it not be better to place the last sign from 300 ft. to 500 ft., if interchanges are not too close to each other, from the "gore" so that the motorist will be forced to make his decision in time to perform a safe merge to the right if he is not already in the proper lane? Then, if he forgets to get in the proper lane, the last minute reminder would not be there to invite him to make a hazardous maneuver and he would have to backtrack to his desired destination the best way possible.

The culprit in the above situation is probably not so often the stranger motorist but is the regular user who allows his driving habits to become lax because of his familiarity with the facility.

It would be valuable to know of any experiences which other engineers might have had with this problem and if such experience has shown that having the last sign at the "gore" is still the best location. Of particular interest in this situation would be any accident experience which might have been accumulated.

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a. Proc. Paper 1627, May, 1958, by George M. Webb.

1. Sr. Traffic Engr., State Bur. of Traffic Safety, Trenton, N. J.

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PROCEEDINGS PAPERS

The technical papers published in the past year are identified by number below. Technical-division sponsorship is indicated by an abbreviation at the end of each Paper Number, the symbols referring to: Air Transport (AT), City Planning (CP), Construction (CO), Engineering Mechanics (EM), Highway (HW), Hydraulics (HY), Irrigation and Drainage (IR), Pipeline (PL), Power (PO), Sanitary Engineering (SA), Soil Mechanics and Foundations (SM), Structural (ST), Surveying and Mapping (SU), and Waterways and Harbors (WW), divisions. Papers sponsored by the Board of Direction are identified by the symbols (BD). For titles and order coupons, refer to the appropriate issue of "Civil Engineering." Beginning with Volume 82 (January 1956) papers were published in Journals of the various Technical Divisions. To locate papers in the Journals, the symbols after the paper numbers are followed by a numeral designating the issue of a particular Journal in which the paper appeared. For example, Paper 1449 is identified as 1449 (HY 6) which indicates that the paper is contained in the sixth issue of the Journal of the Hydraulics Division during 1957.

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c. Discussion of several papers, grouped by divisions.

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